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A LIMITED HANDLING QUALITIES EVALUATION OF AN IN-FLIGHT SIMULATION OF THE 2003 WRIGHT FLYER

HAVE WRIGHT

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JUNE 2001

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PREFACE

This Technical Information Memorandum presents the concept, procedures, and results for the HAVE WRIGHT test project. The project's overall objective was to evaluate the handling qualities of an in-flight simulation of the 2003 Wright Flyer. The Responsible Test Organization was the 412th Test Wing, Edwards AFB California. The execution agency was the HAVE WRIGHT test team from the USAF Test Pilot School Class 00B. The requesting agency was the Los Angeles chapter of the American Institute of Aeronautics and Astronautics, and the support agency was Veridian Engineering. This project was performed during the Test Management Phase of the Test Pilot School curriculum.

The HAVE WRIGHT test team conducted flight tests using the Veridian Variable Stability Learjet 24 In-flight Simulator aircraft at the Air Force Flight Test Center, Edwards Air Force Base, California. The USAF Test Pilot School sponsored this project.

EXECUTIVE SUMMARY

This Technical Information Memorandum presents the concept, procedures, and results for the HAVE WRIGHT test project. The overall test objective was to conduct a limited handling qualities evaluation of an in-flight simulation of the 2003 Wright Flyer at the Air Force Flight Test Center (AFFTC), Edwards AFB California. The Veridian Variable Stability Learjet 24 In-flight Simulator (VVSLIS) aircraft served as the test platform for the in-flight simulation, and six students from the USAF Test Pilot School (TPS) Class 00B conducted the handling qualities evaluation. Flight testing was conducted from 18 - 20 April 2001 and consisted of six sorties, totaling 9.1 hours, in the VVSLIS aircraft. Also, three C-12C Huron target sorties, totaling 4.9 flight hours, were flown in support of HAVE WRIGHT. All test objectives were met.

The Los Angeles chapter of the American Institute of Aeronautics and Astronautics (AIAA) planned to build and fly a replica of the 1903 Wright Flyer to commemorate the 100th anniversary of the historic flight. Since the original Wright Flyer had poor handling qualities and experienced several crashes, the AIAA intended to build a slightly altered "standoff-scale" replica of the Wright Flyer for public flights in 2003. The AIAA "standoff-scale" replica was known as the 2003 Wright Flyer. The design and configuration of the 2003 Wright Flyer was not finalized at the time of the HAVE WRIGHT project.

The test item for the HAVE WRIGHT project was an in-flight simulation of four potential configurations of the 2003 Wright Flyer implemented onboard the VVSLIS aircraft. These configurations were:

1) pitch augmentation OFF, roll augmentation OFF, roll-yaw interconnection ON
2) pitch augmentation ON, roll augmentation OFF, roll-yaw interconnection ON
3) pitch augmentation ON, roll augmentation ON, roll-yaw interconnection ON
4) pitch augmentation OFF, roll augmentation OFF, roll-yaw interconnection OFF

Flight testing focused on low and high bandwidth handling qualities as well as handling qualities associated with low altitude flight and landings. Flight test data consisted of pilot comments, pilot ratings, and time histories of rates and control inputs.

The most important factor affecting the handling qualities of the 2003 Wright Flyer in-flight simulation was whether the pitch augmentation was on or off. When evaluation pilots flew the in-flight simulation without pitch augmentation, the aircraft was difficult to fly and very difficult to land. Lack of pitch augmentation resulted in high pilot workload with pitch pilot in-the-loop oscillations noted. Roll augmentation had no significant positive effect on handling qualities for the tasks evaluated. Lack of roll-yaw interconnection increased pilot workload and degraded handling qualities. As a result of testing, the HAVE WRIGHT team concluded the configuration with pitch augmentation on, roll augmentation off, and roll-yaw interconnection on was the best option for the 2003 Wright Flyer simulation.

The HAVE WRIGHT test program was sponsored by the USAF TPS under direction of the Commandant, USAF TPS. All testing was conducted under job order number M96J0200 with an AFFTC priority code of 6. The Responsible Test Organization was the 412th Test Wing, Edwards AFB. The support agency was Veridian Engineering.

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INTRODUCTION

GENERAL

A limited handling qualities evaluation of an in-flight simulation of the 2003 Wright Flyer was conducted at the Air Force Flight Test Center (AFFTC), Edwards AFB California by students of the USAF Test Pilot School (TPS). The Veridian Variable Stability Learjet 24 In-Flight Simulator (VVSLIS) served as the test platform for the in-flight simulation. Flight testing for this project, referred to as HAVE WRIGHT, was conducted during the Test Management Phase of the TPS curriculum from 18 to 20 April 2001.

This test program was directed by the Commandant, USAF TPS, Edwards AFB California. The Los Angeles chapter of the American Institute of Aeronautics and Astronautics (AIAA) was the requesting agency, and the TPS Education Division (TPS/ED) deputy chief served in a faculty advisory role. All testing was conducted under job order number M96J0200 with an AFFTC priority code of 6. The Responsible Test Organization (RTO) was the 412th Test Wing, Edwards AFB California. The execution agency consisted of three test pilots and three flight test engineers from the USAF TPS Class 00B. The support agency was Veridian Engineering. Key personnel for the HAVE WRIGHT project are listed in Appendix A.

This project required a total of six test sorties at the AFFTC in the VVSLIS test aircraft. Veridian Engineering conducted ground and in-flight software verification testing in Buffalo NY before the aircraft arrived at Edwards AFB. Veridian Engineering also conducted one calibration flight at Edwards AFB to ensure onboard instrumentation and 2003 Wright Flyer simulation software were working properly before flight testing began.

BACKGROUND

In honor of the first controlled and sustained flight of a heavier than air vehicle, the Los Angeles chapter of the AIAA planned to build and fly a "stand-off scale" replica of the 1903 Wright Flyer to commemorate the 100th anniversary of the historic flight.

In March 1999, testing of a full-scale replica of the 1903 Wright Flyer was conducted in the National Aeronautics and Space Administration (NASA) Ames 40' x 80' wind tunnel. This testing yielded stability derivatives for the construction of mathematical state space and transfer function models of the Wright Flyer. These mathematical models formed the foundation for the in-flight simulation of the Wright Flyer aboard the VVSLIS aircraft. Since the Wright Flyer full-scale replica was not intended to fly, it was placed on display in the Federal Aviation Administration building in Hawthorne, California after wind tunnel testing was completed.

Since the original Wright Flyer had poor handling qualities and experienced several crashes, the AIAA planned to build a slightly altered "standoff-scale" replica of the Wright Flyer for public flights in 2003. When viewed from a distance, the AIAA replica was intended to look identical to the original Wright Flyer. However, in the interest of safety, the replica was to be constructed of more robust materials and contain modifications to improve handling qualities. This "standoff-scale" replica was referred to as the 2003 Wright Flyer. Since the design of the 2003 Wright Flyer was not finalized at the time of the HAVE WRIGHT project, the test team evaluated the handling qualities of four potential configurations of the 2003 Wright Flyer via in-flight simulation aboard the VVSLIS aircraft.

TEST ITEM DESCRIPTION

The test item was an in-flight simulation of an aerodynamic math model of the 2003 Wright Flyer. Since the design and configuration of the AIAA 2003 Wright Flyer had not been finalized at the time of the HAVE WRIGHT project, the math model consisted of stability derivatives from wind tunnel tests of the full-scale replica of the 1903 Wright Flyer and stability derivatives from AIAA empirical methods. The 2003 Wright Flyer math model was simulated in the VVSLIS aircraft using onboard software. The stability derivatives and associated state space matrices for the 2003 Wright Flyer math model are shown in Appendix B.

Since feel system models for the 2003 Wright Flyer did not exist at the time of the project, the HAVE WRIGHT test team, with AIAA concurrence, used nominal, linear feel system models for pitch, roll, and yaw control. These linear feel system models were selected from Level 1 flying qualities criteria listed in MIL-STD-1797A, *Flying Qualities of Piloted Aircraft* (Reference 1). To set a common baseline, the linear feel system models were held constant during flight tests to prevent feel system variability from affecting handling qualities evaluations. The linear feel system models were implemented in the VVSLIS aircraft using onboard software.

At the evaluation pilot's seat, the VVSLIS aircraft contained a center control stick for pitch and roll control and foot pedals for yaw control (see Appendix J for further description of the VVSLIS aircraft). The 2003 Wright Flyer's control surface deflection limits, which were provided by AIAA, and the test team's feel system models are listed in Appendix C.

Using the feel system models in Appendix C, the test team evaluated four configurations of the 2003 Wright Flyer simulation (see Table 1). Four configurations were chosen because the HAVE WRIGHT budget limited the project to six flight test sorties. The four configurations evaluated by the test team were also of greatest interest to the AIAA.

Table 1: 2003 Wright Flyer Simulation Configurations

Configuration #	Pitch SAS	Roll SAS	WRI
1	OFF	OFF	ON
2	ON	OFF	ON
3	ON	ON	ON
4	OFF	OFF	OFF

Notes:
1. SAS = Stability Augmentation System.
2. WRI = Warp-Rudder Interconnect.
3. On the VVSLIS aircraft, the Warp-Rudder Interconnect (WRI) was simulated by computer coordination of the ailerons and rudder.
4. The AIAA intended to implement a WRI on the 2003 Wright Flyer. However, the AIAA requested an evaluation of Configuration 4 to explore handling qualities when no augmentation was present.
5. The VVSLIS aircraft configuration was landing gear down and flaps 20% for all flight tests.

The pitch Stability Augmentation System (SAS) consisted of a proportional-plus-integral pitch rate feedback scheme developed by the AIAA. Because of a possible unstable spiral mode and unfavorable lateral gust response, the AIAA also developed a proportional-plus-integral roll rate feedback SAS. Appendix C shows the longitudinal and lateral-directional flight control system schematics along with the command and feedback gains.

Since the original 1903 Wright Flyer incorporated a Warp-Rudder Interconnect (WRI), the VVSLIS simulation included a WRI implemented in the onboard software. The lateral-directional flight control system schematic in Appendix C shows the implementation of the WRI. Since later versions of the Wright Flyer (circa 1908) did not include a WRI, the AIAA also expressed interest in handling qualities without the WRI (as represented by Configuration 4 above).

A major difference between the VVSLIS aircraft in-flight simulation and the 2003 Wright Flyer math model was a speed mismatch of 119 knots. The 2003 Wright Flyer math model was based on a calibrated airspeed of 26 knots and the VVSLIS simulation was based on a calibrated airspeed of 145 knots. The VVSLIS aircraft was incapable of safe flight at Wright Flyer airspeeds, as the normal landing airspeed of the VVSLIS was approximately 125 knots. However, the response of the VVSLIS aircraft to control inputs closely matched the pitch, roll, and yaw rate responses of the 2003 Wright Flyer model for all four configurations. Appendix K shows Veridian's model matching results based on data from Calibration Flight #3 flown at Edwards AFB on 17 April 2001.

Another significant difference between the VVSLIS aircraft and the 2003 Wright Flyer was the setup of the pilot's controls. In the VVSLIS aircraft, the evaluation pilot sat upright in an enclosed cockpit and manipulated an irreversible, hydraulically powered flight control system via a centerstick and foot pedals. The design of the pilot controls

for the 2003 Wright Flyer had not been finalized at the time of the HAVE WRIGHT project. However, the pilot of the actual 2003 Wright Flyer will likely fly in a prone position exposed to the open air and manipulate controls that may not resemble the controls of the VVSLIS aircraft.

TEST OBJECTIVES

The overall test objective was to conduct a limited handling qualities evaluation of an in-flight simulation of the 2003 Wright Flyer. The focus of the handling qualities evaluation was to gather qualitative pilot comments and ratings. All test objectives were met. Specific test objectives were as follows:

1) Practice and refine test techniques for in-flight use with the ground based TPS handling qualities simulator.

2) Evaluate the low and high bandwidth handling qualities of the 2003 Wright Flyer simulation using the VVSLIS aircraft.

3) Evaluate the operational handling qualities of the 2003 Wright Flyer simulation using the VVSLIS aircraft.

TEST AIRCRAFT

The test aircraft was the Veridian Variable Stability Learjet 24 In-flight Simulator (VVSLIS), tail number N101VS. Figure 1 shows the VVSLIS aircraft. The VVSLIS aircraft was a highly modified Learjet 24D that served as a three axis in-flight simulator for flight research. The VVSLIS aircraft included the following capabilities:

1) Variable feel system with centerstick and sidestick controllers
2) Aircraft motion sensors and associated signal conditioning
3) Control system simulation computer
4) Control surface servos
5) Digital configuration control system
6) Engage/disengage and safety monitoring logic
7) Data recording and playback capabilities.

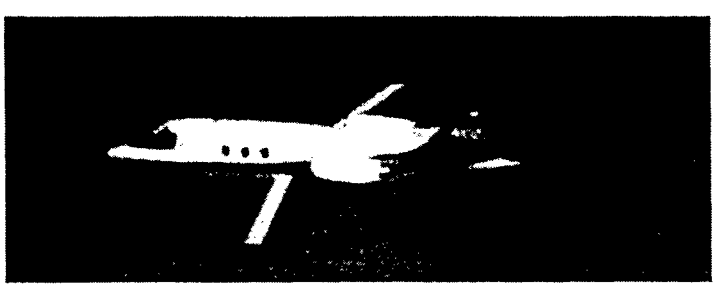


Figure 1 – VVSLIS Aircraft

The right seat evaluation pilot's controls were replaced with components of fly-by-wire (FBW), response feedback, variable stability, and variable control systems. The aircraft commander/safety pilot flew in the left seat with standard Learjet 24 controls. The computerized safety system continually monitored simulation integrity and multiple parameters. If simulation limits were reached or exceeded, the safety system disabled the simulation and reverted aircraft control to the safety pilot. The variable stability system (VSS) automatically disengaged the simulation if any of the following limits were reached:

Maximum Angle of Attack:	+10 deg/-5 deg
Aileron Surface Rate:	200 deg/sec
Maximum Angle of Sideslip:	15 deg
Lateral Acceleration:	+0.3 g
Normal Acceleration:	+2.8 g/+0.15 g
Elevator Surface Rate:	100 deg/sec
Hinge Moments:	Elevator: 680 psi
	Aileron: 550 psi
	Rudder: 660 psi

Note: When the VSS disengaged (manually or automatically), a yellow light flashed on the engage panel and a "beep, beep, beep..." was heard on the interphone and cabin speakers.

In addition, the safety pilot could disable the simulation and take control of the aircraft at any time via several switches in the cockpit. Activation of any of these switches immediately reverted control to the safety pilot. Every time the safety pilot took control, he flew a baseline Learjet 24. Also, in the event the safety pilot became incapacitated or a control cable failure occurred, the evaluation pilot could fly the aircraft with the VSS disengaged using the fly-by-wire (FBW) system and normal Learjet control logic. In this case, all basic Learjet systems were available and the handling characteristics were those of the basic Learjet aircraft with the yaw damper on. A more detailed description of the VVSLIS aircraft can be found in Appendix J and References 2, 3, and 4.

SUPPORT AIRCRAFT

Three C-12C Huron aircraft sorties were used to support the HAVE WRIGHT program. The C-12C acted as target during tracking maneuvers and as photo chase. Test team pilots flew the aircraft with a qualified C-12C instructor pilot from the TPS staff acting as aircraft commander.

INSTRUMENTATION

Since the focus of the project was to gather qualitative pilot comments and ratings, specialized instrumentation and a list of go/no-go instrumentation parameters was not required to meet the test objectives. However, the VVSLIS on board data acquisition system (DAS) was capable of recording multiple instrumentation parameters (such as angles, forces, deflections, and rates), and the DAS was operational for the flight test sorties. The test team used the recorded DAS data to generate plots to support pilot comments and ratings where appropriate. Instrumentation parameters that were recorded by the DAS are listed in Appendix D.

TEST AND EVALUATION

GENERAL

The test team conducted a limited handling qualities evaluation of an in-flight simulation of the 2003 Wright Flyer, investigating the ability of pilots to control the aircraft with and without various levels of augmentation including a pitch Stability Augmentation System (SAS), a roll SAS, and a Warp-Rudder Interconnect (WRI). The in-flight simulation was implemented on the Veridian Variable Stability Learjet 24 In-Flight Simulator (VVSLIS) aircraft. The project's flight test data consisted of qualitative pilot comments, pilot ratings, and time histories of rates and control inputs. From a handling qualities perspective, the flight test data were intended to aid the AIAA in choosing a final configuration for the 2003 Wright Flyer and to provide useful information for future pilots of this aircraft.

Using the feel system models in Appendix C, the test team evaluated four configurations of the 2003 Wright Flyer simulation (see Table 2). Four configurations were chosen because the HAVE WRIGHT budget limited the project to six flight test sorties. The four configurations evaluated by the test team were also of greatest interest to the AIAA.

Table 2: 2003 Wright Flyer Simulation Configurations

Configuration #	Pitch SAS	Roll SAS	WRI
1	OFF	OFF	ON
2	ON	OFF	ON
3	ON	ON	ON
4	OFF	OFF	OFF

Notes:
1. SAS = Stability Augmentation System.
2. WRI = Warp-Rudder Interconnect.
3. On the VVSLIS aircraft, the Warp-Rudder Interconnect (WRI) was simulated by computer coordination of the ailerons and rudder.
4. The AIAA intended to implement a WRI on the 2003 Wright Flyer. However, the AIAA requested an evaluation of Configuration 4 to explore handling qualities when no augmentation was present.
5. The VVSLIS aircraft configuration was landing gear down and flaps 20% for all flight tests.

The pitch SAS consisted of a proportional-plus-integral pitch rate feedback scheme developed by the AIAA. Because of a possible unstable spiral mode and unfavorable lateral gust response, the AIAA also developed a proportional-plus-integral roll rate feedback SAS. Appendix C shows the longitudinal and lateral-directional flight control system schematics along with the command and feedback gains.

Since the original 1903 Wright Flyer incorporated a WRI, Configurations 1, 2, and 3 included a WRI implemented in the onboard software. The lateral-directional flight control system schematic in Appendix C shows the implementation of the WRI. Since later versions of the Wright Flyer (circa 1908) did not include a WRI, the AIAA also expressed interest in handling qualities without the WRI as represented by Configuration 4 above.

In preparation for flight tests, the test team used the ground based TPS handling qualities simulator to refine crew resource management techniques, test efficiency skills, and test procedures. The test team programmed the non-dimensional stability derivatives for the 2003 Wright Flyer math model (see Appendix B) into the USAF TPS flying qualities simulator. Pilot and engineer teams "flew" profiles in the TPS simulator concentrating on test execution efficiency, selection of appropriate analog rating scales, and verbalizing and recording pilot comments. The test team also practiced using Cooper-Harper rating scales and Pilot In-the-Loop Oscillation (PIO) rating scales (see Appendix I, Figures I1 and I2). TPS simulator "flight" profiles included low and high bandwidth maneuvers as well as low altitude flight and landings

Veridian Engineering conducted ground and in-flight software verification testing in Buffalo NY before the VVSLIS aircraft arrived at Edwards AFB CA. To ensure the 2003 Wright Flyer simulation software was working properly, Veridian conducted a final software verification flight (Calibration Flight #3) at Edwards AFB on 17 April 2001. The final software verification flight revealed the simulation was correctly implemented onboard the VVSLIS aircraft for all four configurations. Detailed results of Veridian's software verification testing are shown in Appendix K.

Following the software verification flight, six test sorties (approximately 1.5 hours duration each) were flown in the VVSLIS aircraft. The six test sorties were conducted from 18 - 20 April 2001. All testing was accomplished in day, visual meteorological conditions (VMC). The flight test condition matrix is shown in Appendix E. The test team flew all planned test points in the test condition matrix. The flight test sortie log, which shows the personnel that flew on each sortie, is shown in Appendix F. The Daily/Initial Flight Test Reports for the six test sorties are shown in Appendix H.

Each of the three evaluation pilots had two sorties to evaluate the handling qualities of all four 2003 Wright Flyer simulation configurations. During the flight tests, the evaluation pilots had full knowledge of whether the pitch SAS, roll SAS, and WRI were on or off. The flying experience of the evaluation pilots is summarized in Table 3.

Table 3: HAVE WRIGHT Evaluation Pilot Flying Experience

Pilot Designation	Operational Aircraft Experience	Total Flight Hours
Pilot A	F-16	2,000+
Pilot B	F-16, T-38A	1,900+
Pilot C	F-15	1,500+

OBJECTIVE 1 - TEST TEAM PREPARATION

Practice and refine test techniques for in-flight use with the ground based TPS handling qualities simulator.

Crew Resource Management and Test Efficiency:

Prior to in-flight testing, test team pilots and engineers refined crew resource management and test efficiency skills by practicing proposed test maneuvers using the TPS handling qualities simulator.

Test Procedures:

The test team programmed the non-dimensional stability derivatives for the unaugmented 2003 Wright Flyer math model (see Appendix B) into the USAF TPS flying qualities simulator. The four 2003 Wright Flyer configurations were simulated using the flight control system architecture in Appendix C. Pilot and engineer teams "flew" profiles in the TPS handling qualities simulator concentrating on test execution efficiency, selection of appropriate analog rating scales, and verbalizing and recording pilot comments. The test team also practiced using Cooper-Harper rating scales and Pilot In-the-Loop Oscillation (PIO) rating scales (see Appendix I, Figures I1 and I2). TPS handling qualities simulator "flight" profiles included low and high bandwidth maneuvers as well as operational maneuvers that consisted of low altitude flight and landings.

Low bandwidth maneuvers included: holding straight and level flight, pitch captures of ±5 and ±10 degrees, bank captures of ±10 and ±20 degrees, and heading captures of ±30 degrees. The pilots annotated which bank angle they used to achieve the 30 degrees of heading change and how much overshoot or undershoot occurred. Slowly varying steady heading sideslips were performed for Configuration 4 (pitch SAS off, roll SAS off, WRI off) only. During the low bandwidth maneuvers in the TPS handling qualities simulator, altitude was not a parameter of interest. Since the simulator required re-initialization if the pilot flew into the "virtual" ground, the test team selected any convenient altitude that prevented "virtual" ground impact.

High bandwidth techniques included Handling Qualities during Tracking (HQDT) maneuvers in the pitch and roll axis. For HQDT, the pilot aggressively tracked a simulated

target from a trail position at a range of 1000 feet. Again, simulator altitude was not a parameter of interest.

Low altitude flight and landings were simulated. Low altitude flight included sustained level flight at approximately 100 feet above ground level (AGL) and 20 feet above the virtual runway. Low altitude simulated flight focused on crew procedures and refinement of analog rating scales rather than holding a simulated altitude within tight tolerances. To simulate the operational maneuvers of the 2003 Wright Flyer, landings were initiated after holding sustained level flight (20 feet AGL goal) over the runway. The simulator's runway image contained aimpoint rectangles that defined desired and adequate Cooper-Harper landing performance criteria. Desired and adequate definitions for Cooper-Harper criteria for low altitude flight and landings were as follows:

100 feet AGL level flight:	Hold level flight for at least 30 seconds, desired Hold level flight for at least 15 seconds, adequate
Sustained level flight over the runway (20 feet AGL goal):	Hold level flight for at least 30 seconds, desired Hold level flight for at least 15 seconds, adequate
Landings (from sustained level flight over the runway):	Softly land within +/- 500 feet of the aimpoint and +/- 10 feet of centerline, desired Firmly (or softly) land within +/- 1000 feet of an aimpoint and +/- 20 feet of centerline, adequate

The simulator computed the descent rate at touchdown, and the "softness" or "firmness" of the landing was determined by the descent rate. A descent rate of less than or equal to 1.5 ft/sec at touchdown was considered soft. A descent rate of greater than 1.5 ft/sec and less than 4 ft/sec at touchdown was considered firm. The simulator also computed the longitudinal and lateral landing distance with respect to the aimpoint.

Results, Analyses, and Evaluation:

Test team pilots and engineers refined crew resource management and test efficiency skills by practicing proposed test maneuvers using the TPS handling qualities simulator. As a result of the simulator sessions, the test team finalized the test cards for use on the flight test sorties.

Although the TPS handling qualities simulator did not provide a high fidelity simulation, the fidelity was enough to alert pilots to how quickly the virtual aircraft could deviate from level flight without pilot compensation. Since the non-dimensional pitch stability derivative, Cm_{α}, had an unstable (positive) sign, the simulation without pitch augmentation was statically unstable in pitch as expected. The pitch instability made the simulation difficult to fly and required constant pilot compensation. Without tight pilot control of the pitch axis, the aircraft quickly diverged.

When the pitch Stability Augmentation System (SAS) was on, the virtual aircraft was much easier to fly and did not diverge in pitch. Pilot workload in the pitch axis was low and the aircraft was much more controllable.

The TPS handling qualities simulator also revealed significant adverse yaw tendencies when the virtual aircraft was banked. Turning the aircraft precisely was very difficult, but small roll control inputs to keep the wings level was an effective technique. Adverse yaw was apparent when the roll SAS was on and off.

When pitch SAS was off and Warp-Rudder Interconnect (WRI) was off, pilot workload was extremely high. The aircraft was very difficult to fly and controlling the pitch and yaw axis tended to lead to task saturation. Considerable longitudinal stick and rudder pedal compensation were required to prevent divergence in the pitch and yaw axes.

The primary intent of the TPS handling qualities simulator was to refine crew resource management and test efficiency skills and finalize test cards for in-flight use. The test team's preparation with the TPS handling qualities simulator proved to be beneficial because all in-flight procedures and maneuvers ran smoothly and efficiently aboard the VVSLIS aircraft. As a secondary objective, the test team also hoped the TPS simulator provided at least a basic insight into the handling qualities that would be encountered during the in-flight simulation with the VVSLIS aircraft. After the completion of flight testing, the test team determined the TPS handling qualities simulator did resemble the in-flight simulation, at least on a basic qualitative level (see Objective 3 for further discussion).

OBJECTIVE 2 - LOW AND HIGH BANDWIDTH IN-FLIGHT HANDLING QUALITIES

Evaluate the low and high bandwidth handling qualities of the 2003 Wright Flyer simulation using the VVSLIS aircraft.

Pilot Comments and Ratings for Low Bandwidth Handling Qualities:

The test team qualitatively evaluated the low bandwidth handling qualities of the 2003 Wright Flyer (simulated in the VVSLIS aircraft) using pilot comments and analog rating scales. A build-up approach was implemented to achieve this objective in that low bandwidth handling qualities were evaluated before proceeding to high bandwidth and operational testing.

Test Procedures for Low Bandwidth Handling Qualities:

To evaluate low bandwidth handling qualities, the test team used pitch captures, bank captures, heading captures, pitch and yaw doublets, and slowly varying steady heading sideslips. All maneuvers were performed at 10,000 feet pressure altitude (PA) with the following VVSLIS aircraft configuration: 145 KIAS, landing gear down, flaps at 20%.

Additionally, Wright Flyer Configurations 1, 2, and 3 (WRI on) were flown with the evaluation pilot's feet on the floor to avoid "fighting" the WRI. For Configuration 4 (WRI off), the evaluation pilot actuated the rudder pedals to control yaw. The low bandwidth handling qualities were evaluated with the low bandwidth maneuvers listed in the Flight Test Condition Matrix (Appendix E). Specifically, low bandwidth maneuvers included:

1) Holding straight and level flight
2) Pitch doublets
3) Roll doublets
4) Yaw doublet for configuration 4
5) Pitch captures of 5 and 10 degrees nose up and nose down
6) Bank captures of 10, 15 and 20 degrees left and right
7) Heading captures of 30 degrees left and right
8) For configuration 4 (pitch and roll SAS off and WRI off), slowly varying steady heading sideslips to full left and right rudder pedal deflections

<u>Results, Analyses, and Evaluation for Low Bandwidth Handling Qualities:</u>

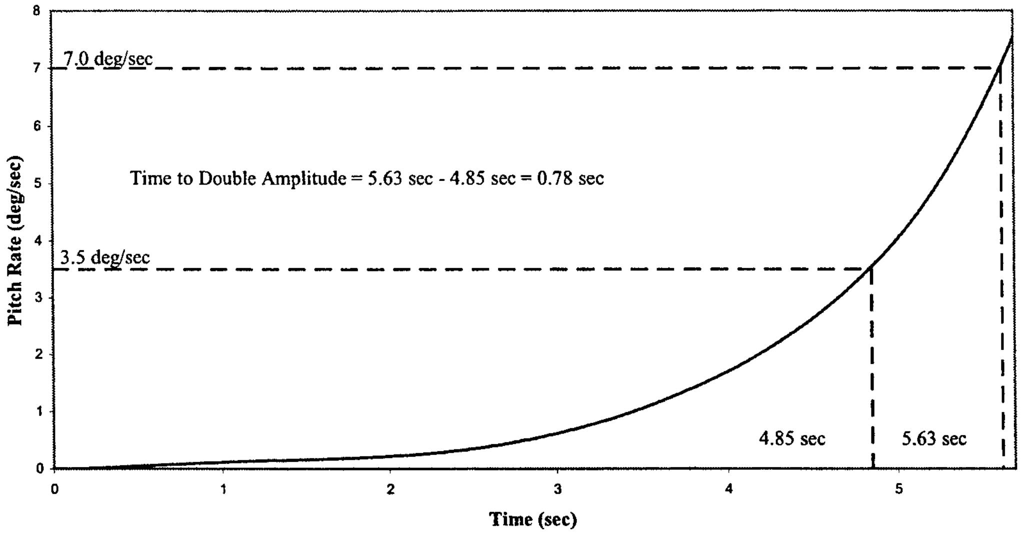
Appendix I contains the completed in-flight analog rating scales for the low bandwidth maneuvers. The analog scales in Appendix I present a qualitative comparison of the low bandwidth handling qualities for the four configurations as evaluated by Pilot A, Pilot B, and Pilot C. The following is a discussion of the low bandwidth testing conducted for the four configurations of the 2003 Wright Flyer in-flight simulation:

1) <u>Holding straight and level flight at 10,000 feet pressure altitude (PA):</u>

The intent of this maneuver was to determine how easily level flight could be maintained with each configuration before attempting the operational tasks of sustained level flight near the ground. Outside visual references were used to maintain level flight. Based on the results of this task, qualitative analog rating scales were completed. These analog scales are located in Appendix I.

While attempting to hold straight and level flight, the test team found undesirable motions in pitch were always present and easily induced in configurations with pitch SAS off. It was readily apparent that without constant, closed-loop pilot control of pitch, the aircraft would diverge almost immediately. Figure 2 shows the divergent open-loop pitch rate response to a small step input with the pitch SAS off.

Figure 2 - Response to Small Step Pitch Input, Pitch SAS Off



With pitch SAS on, holding straight and level flight was much easier. In fact, once a pitch attitude was set, pilot control was not required to maintain level flight. The effects of roll SAS were not evident for the level flight task. Wings-level attitudes were easy to maintain with both roll SAS on and off.

The test team also found that undesirable motions in yaw were always present and easily induced with the WRI off (Configuration 4). The level flight task became substantially more difficult with this configuration, and controlling both the pitch and yaw axes simultaneously caused a very high workload. It was easy to become task saturated while controlling the undesirable motion in one axis and forgetting about the other axis. For instance, trying to maintain lateral nose position with the rudder routinely led to a break down in maintaining level flight in the pitch axis.

2) Pitch Doublets:

The intent of this maneuver was to determine the open-loop pitch response with pitch SAS on and off. Starting from straight and level flight, a doublet input in the pitch axis was performed. Open loop response was observed after the pitch doublet.

The test team found that the aircraft was divergent in pitch in configurations with pitch SAS off. In fact, the aircraft would often diverge in the last direction of the pitch doublet. With the pitch SAS on, the test team found the aircraft to be statically stable in pitch with a heavily damped dynamic response and no overshoots observed.

3) Roll doublets:

The intent of this maneuver was to determine the open loop roll response with roll SAS on and roll SAS off. Starting from straight and level flight, a doublet input in the roll axis was performed. Open loop response was observed after the roll doublet. With the roll SAS on and off, roll doublets produced almost no noticeable bank response due to the extremely slow roll rate. Adverse yaw was pronounced with the roll SAS off and even more pronounced with the roll SAS on.

4) Yaw doublets for Configuration 4:

When the WRI was on for Configurations 1, 2, and 3, the rudder pedals were not used and therefore yaw doublets were not performed. Therefore, yaw doublets were only performed when the WRI was off (Configuration 4). The intent of this maneuver was to determine the open loop yaw response with the pitch and roll SAS off and the WRI off. Starting from straight and level flight, a doublet rudder pedal input was performed. Open loop response was observed after the rudder doublet.

Small yaw doublets excited an extremely "snakey" (as opposed to "rolly") Dutch roll response. If the rudder doublets were too large, the yaw angle diverged and the Variable Stability System (VSS) safety limits disengaged the simulation.

5) Pitch captures of 5 and 10 degrees nose up and nose down:

The intent of this maneuver was to determine how easily pitch attitudes could be achieved and maintained with each configuration. The maneuvers began from straight and level flight. Pitch attitudes of 5 and 10 degrees nose up and nose down were attempted, primarily through using outside references and cross-checking the attitude indicator. Based on the results of this task, qualitative analog rating scales were completed. These scales are located in Appendix I.

The test team found that undesirable motions in pitch were always present and easily induced with the pitch SAS off. Achieving pitch attitudes and maintaining them were substantially more difficult than when the pitch SAS was on.

With the pitch SAS off and WRI off (Configuration 4), workload was very high due to the required active control in the pitch and yaw axes. Onset of pitch response was too abrupt with almost no initial delay, resulting in pitch overshoots of 3 to 4 degrees. It was very easy to become task saturated controlling the undesirable motion in one axis while completely forgetting about the other axis. For instance, trying to maintain lateral nose position with the rudder routinely led to a break down in maintaining pitch attitude.

6) Bank captures of 10, 15, and 20 degrees left and right:

The intent of this maneuver was to determine how easily bank attitudes could be achieved and maintained with each configuration. The maneuvers began from straight and level flight. Various bank attitudes of 10, 15, and 20 degrees left and right were attempted, primarily through using outside references and cross-checking instruments. Based on the results of this task, qualitative analog rating scales were completed. These scales are located in Appendix I.

With the roll SAS off, the roll response was sluggish and bank captures were unpredictable, producing overshoots of up to 5 degrees. Once established in a particular bank attitude, opposite direction lateral stick inputs were required to maintain bank attitude, indicating spiral mode instability.

With roll SAS on, the roll response was also sluggish, but bank captures were slightly more predictable and more precise than when the roll SAS was off. However, adverse yaw was more pronounced with roll SAS on. Once established in a particular bank attitude, almost no opposite direction lateral stick inputs were required to maintain bank attitude, which indicated spiral mode stability.

With pitch SAS off, roll SAS off, and WRI off, bank attitudes were difficult to establish and maintain due to the intense workload in pitch and yaw control. Roll inputs excited large amounts of adverse yaw and a snakey Dutch roll. The Dutch roll tendencies could be damped with rudder pedal inputs, however, bank control suffered. Bank attitudes were unpredictable and were easily overshot by 5 degrees. Once established in a particular bank attitude, opposite direction lateral stick inputs were required to maintain bank attitude, which indicated spiral mode instability.

7) Heading captures of 30 degrees left and right

The intent of this maneuver was to determine how easily precise heading changes could be achieved and maintained with each configuration. The maneuvers began from straight and level flight. Various heading changes of up to 30 degrees left and right were attempted, primarily through using outside references and cross-checking instruments. Based on the results of this task, qualitative analog rating scales were filled out. These scales are located in Appendix I.

With pitch SAS off, roll SAS off, and WRI on (Configuration 1), heading captures were easy to accomplish with approximately 15-30 degrees of bank and 5 degrees of lead to roll out within +/- 2 degrees of intended heading.

With pitch SAS on, roll SAS off, and WRI on (Configuration 2), heading captures were also easy to accomplish with 15-30 degrees of bank and 10 degrees of lead to roll out within +/- 2 degrees of intended heading.

With pitch SAS on, roll SAS on, and WRI on (Configuration 3), adverse yaw was more pronounced and heading captures were more difficult than the previous two configurations. Heading captures required 15-20 degrees of bank and almost 15 degrees of lead to roll out +/- 5 degrees of intended heading. Overshoots of 10 degrees were common.

With pitch SAS off, roll SAS off, and WRI off (Configuration 4), undesirable motions in yaw were always present and easily induced. Heading captures were much more difficult to achieve than with the other three configurations. Heading control was completely unpredictable due to large yaw rates and a snakey Dutch roll. Heading control in this configuration was at best +/- 30 degrees of intended heading. Workload was intense just keeping the aircraft under control.

8) Slowly varying steady heading sideslips with full left and right rudder pedal deflections:

When the WRI was on for Configurations 1, 2, and 3, the rudder pedals were not used and therefore steady heading sideslips were not performed. Since sideslip was induced with the use of rudder pedals, steady heading sideslips were only performed when the WRI was off (Configuration 4). The intent of the steady heading sideslips was to determine how much bank was required for a particular amount of sideslip to maintain a steady heading. These maneuvers began from straight and level flight, and a small amount of rudder was input with a commensurate amount of bank to maintain a steady heading. The maneuver continued until full rudder was reached or the VSS safety system disengaged the simulation. Based on the results of this task, qualitative analog rating scales were completed. These scales are located in Appendix I.

During the steady heading sideslip maneuvers, the VSS safety system disengaged the simulation at approximately 75% left or right rudder pedal deflection. While applying rudder, opposite bank induced adverse yaw, which caused the nose of the aircraft to continue in the direction of rudder input. Once opposite bank was established, lateral stick force in the same direction as rudder pedal input was required to maintain a steady heading. During the steady heading sideslips, the maximum bank angle obtained prior to VSS disengagement was 15 degrees.

Pilot comments and ratings for high bandwidth handling qualities:

The test team qualitatively evaluated the high bandwidth handling qualities of the 2003 Wright Flyer (simulated in the VVSLIS aircraft) using pilot comments, analog rating scales, and PIO ratings. The high bandwidth maneuvers aided in evaluating each configuration throughout an achievable frequency and amplitude spectrum of control inputs. By using high bandwidth maneuvers to evaluate each configuration, areas of potential problems could surface that were not revealed during low bandwidth maneuvers. The high bandwidth handling qualities were evaluated before proceeding to operational testing.

Test Procedures for High Bandwidth Handling Qualities:

To evaluate high bandwidth handling qualities, the test team used Handling Qualities during Tracking (HQDT) techniques with a C-12 target aircraft. HQDT techniques involved using a fixed pipper sight in the test aircraft as a reference point to track a target aircraft at ranges from 500 to 1000 feet. HQDT tasks were executed in both the pitch and roll axes. Additionally, simulated flare and pitch attitude tracking tasks were performed. The high bandwidth handling qualities were evaluated with maneuvers listed in the Flight Test Condition Matrix (Appendix E). Specifically, high bandwidth maneuvers were performed at 10,000 feet pressure altitude (PA) for all four configurations and included:

1) Pitch HQDT task: The intent of this maneuver was to explore a spectrum of pitch inputs to determine any possible areas of concern. With the target aircraft maintaining straight and level flight at 500-1000 feet in front of the test aircraft, the test aircraft was offset from the target aircraft either high or low. The high or low offset was approximately one target aircraft wingspan from the fixed pipper location in the reticle on the VVSLIS test aircraft. Once the offset was established, a step input in pitch was made in the direction to put the pipper on the target, and the step input was held until the pipper deviated to the other side of the target. At that precise moment, a reverse step input was made to correct the pipper error and drive the pitch in the other direction. The step input was held until the pipper passed through the target and an error developed in the other direction. This process repeated itself progressing from low to high frequency inputs until 30 seconds had elapsed. The entire time, the target aircraft maintained straight and level flight. After the pitch HQDT task, Pilot In-the-Loop Oscillation (PIO) ratings (based on the PIO scale in Appendix I) were assigned and analog rating scales were completed.

2) Roll HQDT task: The intent of this maneuver was to explore a spectrum of bank inputs to determine any possible areas of concern. The target aircraft slowly alternated between +/- 10 degrees of bank at 500-1000 feet in front of the test aircraft while the evaluation pilot attempted to match the target's bank angle. A step input in roll was made in the direction to match the target's bank angle, and the step input was held until the bank angle deviated to the other side of the target. At that precise moment, a reverse step input was made to correct the bank angle error and drive the roll in the other direction. The step input was held until the bank angle passed through the target and an error developed in the other direction. This process repeated itself progressing from low to high frequency inputs until 30 seconds had elapsed. After the roll HQDT task, Pilot In-the-Loop Oscillation (PIO) ratings (based on the PIO scale in Appendix I) were assigned and analog rating scales were completed.

3) Simulated flare task: The intent of this maneuver was to investigate the control inputs required and subsequent aircraft response during a simulated flare to landing. The VVSLIS test aircraft established 50 to 100 feet lateral separation from the target aircraft with nose-tail clearance maintained from test to target aircraft. This position was approximately 45-60 degrees aft of the target aircraft's wing line. The VVSLIS

test aircraft was also positioned approximately 20 feet higher in altitude than the target aircraft. A nose down input in pitch was then made to simulate a landing attempt from 20 feet AGL level flight. Using the target aircraft's position relative to the horizon as a reference, a flare was simulated by decreasing nose down pitch. After the simulated flare task, Pilot In-the-Loop Oscillation (PIO) ratings (based on the PIO scale in Appendix I) were assigned and analog rating scales were completed

4) Pitch attitude tracking task: This maneuver was executed immediately after the simulated flare task and was intended to explore translational motion response. While the test aircraft maintained 50 to 100 feet lateral separation off the target aircraft's wing, the target began a 5 degree nose-low pitch descent. A step input in pitch was then made in the direction to match the target's flight path angle, and the step input was held until the test aircraft's flight path angle deviated to the lower side of the target. At that precise moment, a reverse step input was made to correct the error and drive the flight path angle in the other direction. The step input was held until the test aircraft's flight path angle matched the target's flight path angle and an error developed in the other direction. This process repeated itself progressing from low to high frequency inputs until 30 seconds had elapsed. After the pitch attitude tracking task, Pilot In-the-Loop Oscillation (PIO) ratings (based on the PIO scale in Appendix I) were assigned and analog rating scales were completed.

Results, Analyses, and Evaluation for High Bandwidth Handling Qualities:

Appendix I contains the completed in-flight analog rating scales for the high bandwidth maneuvers. The analog scales in Appendix I present a qualitative comparison of the high bandwidth handling qualities for the four configurations as evaluated by Pilot A, Pilot B, and Pilot C. Pilot In-the-Loop Oscillation (PIO) ratings were assigned using the PIO rating scale in Figure I2 (see Appendix I). The following is a discussion of the high bandwidth testing conducted for the four configurations of the 2003 Wright Flyer in-flight simulation:

During all high bandwidth pitch tasks, the test team found undesirable motions in pitch were always present and easily induced in configurations with the pitch SAS off (Configurations 1 and 4). These tasks produced PIO ratings as high as 5, which indicated divergent pitch PIO existed during abrupt or tight control. With pitch SAS off, pitch response was unpredictable and was very sensitive to higher frequency control inputs. Conversely, with pitch SAS on, PIO ratings ranged from 1 to 2, which indicated only minor undesirable motions tended to occur.

With roll SAS on (Configuration 3), adverse yaw was more pronounced than with roll SAS off. For Pilot A, adverse yaw made yaw response to roll control inputs more unpredictable and increased yaw PIO tendencies during the roll HQDT task. With the roll SAS on, Pilot A gave the roll HQDT task a PIO rating of 4, which indicated bounded PIO existed during abrupt or tight control. However, Pilots B and C gave the roll HQDT task PIO ratings of 1 and 2, respectively.

The test team found that undesirable motions in yaw were always present and easily induced with pitch SAS off, roll SAS off, and WRI off (Configuration 4) during all high bandwidth tasks. These maneuvers produced PIO ratings as high as 5, which indicated divergent PIO existed during abrupt or tight control. While all pilots found this configuration the most difficult to control, Pilot A found the ability to control adverse yaw with rudder pedals a positive characteristic. All pilots found they needed to actively control the rudder or they would lose aircraft control. The VSS safety system disengaged the simulation numerous times during the high bandwidth tasks for Configuration 4.

Overall Assessment of Low and High Bandwidth Handling Qualities:

The test team found significant handling qualities differences between the four configurations. All pilots agreed the low and high bandwidth maneuvers were more controllable and required far less workload when the pitch SAS was on (Configurations 2 and 3). However, there were differing opinions on the utility of the roll SAS. Although more adverse yaw was present with the roll SAS on, Pilot B liked the spiral mode stability the roll SAS offered. Pilots A and C perceived roll response to be more sluggish and adverse yaw to be objectionable with roll SAS on, and they preferred the roll SAS to be off. All pilots found the configuration with pitch SAS off, roll SAS off, and WRI off (Configuration 4) to be the most difficult to fly. Maintaining control of the pitch and roll axes simultaneously resulted in very high pilot workload and poor handling qualities.

Based on the low and high bandwidth test results, each pilot rank ordered the four configurations from easiest to hardest to fly. Each pilot proceeded to the operational tasks (specified in Objective 3) starting with the configuration he had rank ordered as easiest to fly. Table 4 summarizes the rank ordered preferences of the three evaluation pilots.

Table 4: Evaluation Pilot Preferences

	Pilot A	Pilot B	Pilot C
Config 1: **Pitch SAS Off** **Roll SAS Off** **WRI On**	3rd	3rd	3rd
Config 2: **Pitch SAS On** **Roll SAS Off** **WRI On**	1st	2nd	1st
Config 3: **Pitch SAS On** **Roll SAS On** **WRI On**	2nd	1st	2nd
Config 4: **Pitch SAS Off** **Roll SAS Off** **WRI Off**	4th	4th	4th

Notes:
1. A "1st" indicates easiest to fly, a "4th" indicates hardest to fly
2. Pilot preferences are based on low and high bandwidth testing only

OBJECTIVE 3 - OPERATIONAL IN-FLIGHT HANDLING QUALITIES

Evaluate the operational handling qualities of the 2003 Wright Flyer simulation using the VVSLIS aircraft.

Pilot Comments and Ratings for Operational Handling Qualities:

The test team qualitatively evaluated the operational handling qualities of the 2003 Wright Flyer simulation using pilot comments, Pilot In-the-Loop Oscillation (PIO) ratings, and Cooper-Harper ratings (see Appendix I for the PIO and Cooper-Harper rating scales). The operational handling qualities were evaluated during the low altitude flight and landing maneuvers listed in the Flight Test Condition Matrix (Appendix E).

Test Procedures:

Based on the low and high bandwidth testing, each evaluation pilot rank ordered the overall handling qualities of the four Wright Flyer configurations from easiest to hardest to fly. The configuration with the best ranking was the first one the evaluation pilot investigated during operational maneuvers near the ground. The rank ordering of the configurations was a matter of evaluation pilot opinion, and one pilot's favorite configuration did not necessarily match another pilot's. Operational maneuvers for the in-flight simulation of the 2003 Wright Flyer included: holding straight and level flight at 100

feet above ground level (AGL), sustained level flight over the runway (20 feet AGL goal), and landing after sustained level flight over the runway. Desired and adequate definitions for Cooper-Harper criteria were:

100 feet AGL level flight:	Hold level flight for at least 30 seconds, desired Hold level flight for at least 15 seconds, adequate
Sustained level flight over the runway (20 feet AGL goal):	Hold level flight for at least 30 seconds, desired Hold level flight for at least 15 seconds, adequate
Landings:	From sustained level flight over the runway (20 feet AGL goal), softly land within +/- 500 feet of an aimpoint and +/- 10 feet of centerline, desired From sustained level flight over the runway (20 feet AGL goal), firmly (or softly) land within +/- 1000 feet of an aimpoint and +/- 20 feet of centerline, adequate

Notes:
1. The VVSLIS aircraft did not have a radar altimeter. For low altitude flight and landings, the evaluation pilot and Veridian safety pilot estimated altitude by looking outside at visual references. The evaluation pilot qualitatively judged his ability to stay "level" while the Test Conductor recorded time.

2. The Veridian Safety Pilot qualitatively assessed landings as "Soft", "Firm", or "Hard".

The operational maneuvers were flown using a build-up approach. Low and high bandwidth handling qualities were evaluated well above the ground for each configuration prior to commencing operational maneuvers. The configuration with the best handling qualities at altitude (as specified in Objective 2) was flown first during operational maneuvers at low altitude. Straight and level flight at 100 feet AGL was accomplished prior to the sustained level flight over the runway (20 feet AGL goal) and landing maneuvers.

1) Straight and level flight at 100 feet AGL: The intent of this maneuver was to evaluate the handling qualities of each configuration during an operationally representative maneuver using outside visual references for maintaining straight and level flight. This maneuver was also used as a build-up to follow-on operational maneuvers. The tower flyby line at Edwards AFB was utilized for this maneuver because it provided excellent visual references in horizontal and vertical space for straight and level flight at 100 feet AGL. In-flight simulations began while roughly aligned with the flyby line at altitudes between 500 and 1,000 feet AGL. Once the Variable Stability System (VSS)

was engaged, a controlled descent was flown to 100 feet AGL. After leveling off using visual references, straight and level flight was continued for as long as possible, or 30 seconds, whichever occurred first. At the completion of the maneuver, a slight pitch up was executed to a climbout attitude prior to the safety pilot disengaging the VSS system.

2) Sustained level flight over the runway (20 feet AGL goal): The intent of this maneuver was also to evaluate the handling qualities of each configuration during an operationally representative maneuver using outside visual references as a primary indication for maintaining straight and level flight. The runway environment provided excellent visual references in vertical space for level flight at approximately 20 feet AGL. In-flight simulations began while roughly aligned with the landing runway at altitudes between 500 and 1,000 feet AGL. Once the VSS was engaged, the aircraft was flown in a controlled descent toward the runway. After leveling off using visual references, straight and level flight was continued for as long as possible, or 30 seconds, whichever occurred first. At the completion of this maneuver, the landing maneuver was begun.

3) Landing after sustained level flight over the runway: The intent of this maneuver was to evaluate the handling qualities of each configuration during landing. The landing maneuver began immediately following the sustained level flight over the runway maneuver. A landing spot was chosen 2,000 to 3,000 feet down the runway, typically abeam a distance remaining marker, and a slow descent was initiated with the goal of landing softly on the landing spot and on the runway centerline. The maneuver typically concluded with a landing, but occasionally, the maneuver was aborted prior to landing. The landings were flown with constant applied power to eliminate moments from thrust effects.

Results, Analyses, and Evaluation

Each evaluation pilot flew all three operational maneuvers with all four configurations. Cooper-Harper ratings and PIO ratings were assigned and analog rating scales were also completed after each operational maneuver. The completed analog scales in Appendix I present a qualitative comparison of the operational handling qualities for the four configurations as evaluated by Pilot A, Pilot B, and Pilot C. Appendix H contains Daily/Initial Flight Test Reports for the flight test sorties.

A total of 64 operational maneuvers were flown, 13 at 100 feet AGL, 28 at 20 feet AGL, and 23 attempted landings. The maneuvers were nearly evenly split between the three evaluation pilots and between the four configurations. The operational maneuvers were accomplished with varying wind conditions ranging from a direct headwind at 20 knots with gusts to 28 knots to crosswinds of approximately 6 knots. Table 5 shows the number of landings that were attempted and completed for each of the four 2003 Wright Flyer simulation configurations.

Table 5: Number of Landings in Each Configuration

	CONFIGURATION 1 PITCH SAS OFF ROLL SAS OFF WRI ON		CONFIGURATION 2 PITCH SAS ON ROLL SAS OFF WRI ON		CONFIGURATION 3 PITCH SAS ON ROLL SAS ON WRI ON		CONFIGURATION 4 PITCH SAS OFF ROLL SAS OFF WRI OFF	
	Number Landings Attempted	Number Landings Completed	Number Landings Attempted	Number Landings Completed	Number Landings Attempted	Number Landings Completed	Number Landings Attempted	Number Landings Completed
Pilot A	2	2	2	2	2	2	2	2
Pilot B	2	1	2	2	2	2	1	0
Pilot C	2	2	2	2	2	2	2	0
Total	**6**	**5**	**6**	**6**	**6**	**6**	**5**	**2**

Note: A completed landing was defined as a landing where the evaluation pilot flew to touchdown without safety pilot intervention or without abandoning the landing task because of unacceptable handling qualities.

Overall, the test team found that all four configurations were controllable for the task of level, non-maneuvering flight. Predictably, as pilot gains increased, all configurations were more susceptible to over-controlling as they were flown closer to the ground. All four configurations could be landed. However, only Pilot A was able to land the configuration with pitch SAS off, roll SAS off, and WRI off (Configuration 4). Pilot A used a yaw "dithering" technique which consisted of high frequency, small amplitude left and right inputs with the rudder pedals, and this tended to prevent divergent aircraft motion in the yaw axis. Figure G18 (Appendix G) shows a time history of Pilot A's yaw dithering technique with the WRI off (Configuration 4) as compared to the WRI command signal with the WRI on (Configuration 1).

For all landings, pilot gains were increased by the requirement for a spot landing within a desired or adequate distance, and higher gains tended to cause over-controlling. Also, a small learning curve was evident after the evaluation pilot's first landing of the day. The first landing of the day in the VVSLIS aircraft tended to result in poorer landing performance (harder landings and/or longer landings) and poorer Cooper-Harper ratings. Figures G1 and G2 show histograms of Cooper Harper ratings for the sustained level flight over the runway task and landing task, respectively. Configurations with pitch SAS on (Configurations 2 and 3) tended to have better Cooper-Harper ratings than configurations with the pitch SAS off (Configurations 1 and 4).

The test team found that a variety of factors led to consistently long landings. Only one of the 19 completed landings was on or short of the planned aimpoint. Landings were long even with headwinds of 20 knots with gusts up to 28 knots. Contributing factors to the long landings included: use of a very shallow flight path, the fact that power was not reduced, and the evaluation pilots' lack of landing currency in the VVSLIS aircraft. Power was held constant during landings to prevent thrust effects from becoming a variable in the simulation. Because power remained constant through the

landing, landing techniques involving flaring were not effective. Attempts to reduce sink rate and increase drag just prior to touchdown by increasing angle of attack often resulted in ballooning and/or "porpoising". As a result, the test team found it difficult to achieve soft landings on a longitudinally precise spot using a shallow flight path angle. Soft landings and precise landings were mutually exclusive. The test team found that predicting the touchdown point was difficult, and forcing the aircraft down to achieve a precise spot landing was unnatural and uncomfortable and typically resulted in firm or hard landings. Soft landings with a sacrifice of precision were less difficult, especially with the pitch SAS on.

The test team found that with pitch SAS off, undesirable pitch motions were always present and PIO existed. Assigned PIO ratings for operational maneuvers were always 3 or greater with the pitch SAS off. With the pitch SAS on, PIO ratings were usually 1 or 2 with two occurrences of a 3 rating. Figures G3 and G4 (Appendix G) show histograms of pitch PIO ratings for the sustained level flight over the runway task and landing task, respectively. With pitch SAS off, the divergent pitch tendency drove undesirable pitch motions and forced a requirement for tight pitch control. It was possible to fly fairly smoothly in pitch, but it required considerable pilot compensation to detect the diverging pitch rate early and precisely offset it with a small step input. If the step input was too large, an uncomfortable pitch overshoot and accompanying divergence occurred. Another more pro-active technique that proved to be effective was constant high frequency, small amplitude "dithering" of the control stick. Although this technique required constant motion of the stick, pitch divergence was avoided.

With pitch SAS off, pitch PIOs presented a significant challenge for the evaluation pilots. Pitch PIOs during landing were experienced by two of the three evaluation pilots when the pitch SAS was off. These PIOs resulted in safety pilot intervention and discontinuation of the simulation or abandonment of the landing task. Pitch PIO tendencies were also noted during level flight. The PIOs during level flight were less frequent and were accompanied by slight climbs. During level flight, the PIO recovery technique was to start a gentle climb to provide a margin for error and then consciously reduce the size of the control inputs to subdue the PIO. The pilots could not simply freeze or release the controls to recover from PIO because the aircraft was divergent in pitch.

Figures G5 through G7 (Appendix G) show longitudinal stick deflection histograms for the three evaluation pilots during landing. These histograms show the pilots spent more time open-loop at zero stick deflection when the pitch SAS was on. When the pitch SAS was off, the histograms show the pilots spent their time alternating between fore and aft stick deflections to control the divergent pitch tendency. Figures G12 through G14 show pitch axis time histories for each pilot when the pitch SAS was off compared to when the pitch SAS was on during landing. The time histories show highly oscillatory pilot stick inputs and pitch rates when the aircraft was statically unstable with pitch SAS off.

The overall handling qualities suffered with pitch SAS off. For the operational maneuvers, Cooper-Harper ratings ranged from 5 to 10 with pitch SAS off and workload was high. With pitch SAS on, Cooper-Harper ratings ranged from 3 to 5 except one rating was a 7 because the landing occurred 200 feet beyond the cutoff distance for adequate performance. Open loop or semi-open loop techniques were possible for the operational tasks with pitch SAS on, and the aircraft was much more predictable and comfortable to fly. The flight path angle could be precisely set and finely adjusted for soft landings. With pitch SAS off, the actual 2003 Wright Flyer will likely have continuous undesirable motions in pitch and require tight control. As a result, PIO will likely occur and consistent soft landings will likely be difficult to achieve.

Pitch SAS should be a requirement for the 2003 Wright Flyer. (R1)[1]

The test team found that handling qualities during level, non-maneuvering flight and landing were very similar with roll SAS on and off (Configurations 2 and 3). For the operational maneuvers, the Cooper-Harper ratings tended to range from 3 to 5 with and without roll SAS as long as the pitch SAS was on (see Figures G1 and G2). One landing with roll SAS off was assigned a Cooper-Harper rating of 7 because it occurred 200 feet beyond the longitudinal cutoff distance for adequate performance; however, pilot workload was tolerable. There were no lateral PIOs observed with roll SAS on or off. However, one pilot felt that undesirable motions tended to occur in the roll axis with the roll SAS off. With roll SAS on, two pilots felt that roll response was decreased and adverse yaw was increased and objectionable. The lateral precision of landings was not affected by roll SAS even when crosswinds were encountered.

The recorded quantitative data also did not show a significant difference between the roll SAS off and roll SAS on configurations (Configurations 2 and 3). Figures G8 through G10 (Appendix G) show lateral stick deflection histograms for the three evaluation pilots during landing. Since the pitch SAS remained on, there was no significant difference between Configuration 2 and Configuration 3 histograms for each individual pilot. Figures G15 through G17 show roll axis time histories for each pilot when the roll SAS was off compared to when the roll SAS was on during landing. As long as the pitch SAS was on, there was no significant difference between Configuration 2 and Configuration 3 roll axis time histories for each individual pilot.

For level non-maneuvering flight and straight-ahead landings, the test team did not see any significant benefit from the roll SAS. Unlike the pitch SAS, the roll SAS did not have a dramatic effect on handling qualities. The qualitative and quantitative data showed the roll SAS did not significantly affect the handling qualities of the 2003 Wright Flyer simulation.

The test team found that handling qualities during operational tasks were degraded when the roll and yaw axes were disturbed by a control input or gust. All configurations

[1]Numerals preceded by an R within parentheses at the end of a paragraph correspond to the recommendation numbers tabulated in the Conclusions and Recommendations section of this report

suffered from an annoying, poorly damped, "snakey" (as opposed to rolly) Dutch roll. The aircraft tended to wander in yaw and precision of the operational tasks suffered. This was especially uncomfortable when very close to the ground during the landing maneuver. However, a technique of using small, slow rolls to level the wings was effective in minimizing the Dutch roll. Because of the annoying Dutch roll, lateral and directional control inputs on the 2003 Wright Flyer should be minimized.

Flight of the 2003 Wright Flyer in crosswinds and gusts should be avoided due to the natural excitation of an annoying Dutch roll mode. (R2)

Landings of the 2003 Wright Flyer should be planned in a wide area to avoid the need for large roll control inputs. Roll inputs should be small and only as required to level the wings. (R3)

The test team found that handling qualities with pitch SAS off, roll SAS off, and WRI off (Configuration 4) were unsatisfactory for level, non-maneuvering flight and landings. In addition to having the poorest handling qualities, this configuration also resulted in the highest pilot workload requirement. Undesirable motions in pitch and yaw were always present and pitch and yaw PIO tendencies were apparent. Cooper-Harper ratings ranged from 6 to 10 and PIO ratings ranged from 3 to 6 (see Figures G1 through G4). Five landings were attempted with this configuration, but only two landings were completed. Only one of three pilots was able to land with this configuration by using a constant yaw dithering technique. The other two pilots used a more reactionary technique of keeping a tightly closed loop for detecting small errors in pitch or yaw and correcting them with equally small control inputs. However, both of these pilots experienced situations with small errors and inputs in the pitch and yaw axes, and then in an instant, the errors and inputs grew and a PIO rapidly developed.

Figures G18 through G20 show yaw input and yaw response time histories for each pilot when the WRI was off and on (Configurations 4 and 1). These figures show that when WRI was off, the pilot needed to actively control yaw with the rudder pedals to replace the command signal that existed when WRI was on. When compared to Pilot B and Pilot C's rudder pedal inputs (WRI off), Pilot A's yaw dithering technique is readily apparent in Figure G18. In addition, when the WRI was off, the rudder pedal deflection histograms in Figure G11 show Pilot A consistently dithering the rudder pedals while Pilot B and Pilot C were somewhat sporadic with the rudder pedals.

With the WRI off and pitch SAS off (Configuration 4), controlling both the pitch and yaw axes simultaneously resulted in a very high workload. It was easy to become task saturated while controlling the undesirable motion in one axis and forgetting about the other axis. This simulation configuration definitely resulted in the worst handling qualities.

In summary, the most important factor affecting the handling qualities of the 2003 Wright Flyer in-flight simulation was whether the pitch augmentation was on or off. When the in-flight simulator was flown with pitch augmentation off, the aircraft was

difficult to fly and very difficult to land. Lack of pitch augmentation resulted in high pilot workload with pitch PIO noted. Roll augmentation had no significant positive effect on handling qualities for the tasks evaluated. The configuration with pitch SAS off and WRI off resulted in unsatisfactory handling qualities and very high pilot workload.

Based on operational test results, each pilot rank ordered the four configurations from easiest to hardest to fly. Table 6 summarizes the final preferences of the three evaluation pilots.

Table 6: Evaluation Pilot Final Preferences

	Pilot A	Pilot B	Pilot C
Config 1: Pitch SAS Off Roll SAS Off WRI On	3rd	3rd	3rd
Config 2: Pitch SAS On Roll SAS Off WRI On	1st	2nd	1st
Config 3: Pitch SAS On Roll SAS On WRI On	2nd	1st	2nd
Config 4: Pitch SAS Off Roll SAS Off WRI Off	4th	4th	4th

Note: A "1st" indicates easiest to fly, a "4th" indicates hardest to fly

As a final note, the test team found that the use of a ground-based simulator was effective for flight crew preparation prior to actual flight. The team felt that ground-based simulation provided valuable insight into basic handling qualities, timing, and workload for the in-flight maneuvers. The handling qualities of the four Wright Flyer configurations were significantly different from handling qualities of modern aircraft. Flying techniques successfully employed on other airplanes were not necessarily appropriate for the Wright Flyer configurations. Since the actual 2003 Wright Flyer will not have a safety system to "disengage the simulation" nor have a safety pilot aboard, preparation on the ground will be vitally important.

A ground-based simulator should be used in preparation for the first flight of the 2003 Wright Flyer. (R4)

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CONCLUSIONS AND RECOMMENDATIONS

The test team conducted a limited handling qualities evaluation of an in-flight simulation of four possible configurations of the 2003 Wright Flyer. The four simulation configurations consisted of various levels of control augmentation. Augmentation systems included a pitch Stability Augmentation System (SAS), a roll SAS, and a Warp-Rudder Interconnect (WRI). The in-flight simulation was implemented on the Veridian Variable Stability Learjet 24 In-Flight Simulator (VVSLIS) aircraft. The project's flight test data consisted of qualitative pilot comments, pilot ratings, and time histories of rates and control inputs. From a handling qualities perspective, the flight test data were intended to aid the American Institute of Aeronautics and Astronautics (AIAA) in choosing a final configuration for the 2003 Wright Flyer and to provide useful information for future pilots of this aircraft. All test objectives were met.

The most important factor affecting the handling qualities of the 2003 Wright Flyer in-flight simulation was whether the pitch augmentation was on or off. When the in-flight simulation was flown with pitch augmentation off, the aircraft was difficult to fly and very difficult to land. Lack of pitch augmentation resulted in high pilot workload with moderate pitch PIO noted. Roll augmentation had no significant positive effect on handling qualities for the tasks evaluated. The configuration with pitch SAS off and WRI off resulted in unsatisfactory handling qualities and very high pilot workload.

With pitch SAS off, undesirable pitch motions were easily induced. The aircraft was statically unstable, and the divergent pitch tendency drove undesirable pitch motions and forced a requirement for tight pitch control. It was possible to fly fairly smoothly in pitch, but it required considerable pilot compensation to detect the diverging pitch rate early and precisely offset it with a small step input. If the step input was too large, an uncomfortable pitch overshoot and accompanying divergence occurred. Another more pro-active technique that proved to be effective was constant high frequency, small amplitude "dithering" of the control stick. Although this technique required constant motion of the stick, pitch divergence was avoided.

With pitch SAS off, pitch PIOs presented a significant challenge for the evaluation pilots. Pitch PIOs during landing were experienced by two of the three evaluation pilots when the pitch SAS was off. These PIOs resulted in safety pilot intervention and discontinuation of the simulation or abandonment of the landing task. Pitch PIO tendencies were also noted during level flight.

When pitch SAS was on, the aircraft was much more predictable and comfortable to fly. The aircraft was statically stable, and the pitch response was heavily damped. The flight path angle could be precisely set and finely adjusted for soft landings. Pitch handling qualities improved and pilot workload greatly decreased when the pitch SAS was on.

<u>Recommendation 1.</u> Pitch SAS should be a requirement for the 2003 Wright Flyer. (Page 25)

A variety of factors led to consistently long landings. Only one of the 19 completed landings was on or short of the planned aimpoint. Landings were long even with headwinds of 20 knots with gusts up to 28 knots. Contributing factors to the long landings included: use of a very shallow flight path, the fact that power was not reduced, and the evaluation pilots' lack of landing currency in the VVSLIS aircraft. Because power remained constant through the landing, landing techniques involving flaring were not effective. Attempts to reduce sink rate and increase drag just prior to touchdown by increasing angle of attack often resulted in a ballooning and/or "porpoising". As a result, it was difficult to achieve soft landings on a longitudinally precise spot using a shallow flight path angle. Soft landings and precise landings were mutually exclusive. Predicting the touchdown point was difficult, and forcing the aircraft down to achieve a precise spot landing was unnatural and uncomfortable and typically resulted in firm or hard landings. Soft landings with a sacrifice of precision were less difficult, especially with the pitch SAS on.

The roll SAS provided no significant benefit to handling qualities. With roll SAS on, two pilots felt that roll response was decreased and adverse yaw was increased and objectionable. One pilot liked the spiral mode stability the roll SAS offered, but he objected to the increased adverse yaw. The lateral precision of landings was not affected by roll SAS even when crosswinds were encountered. For level, non-maneuvering flight and straight-ahead landings, the test team did not see any significant benefit from the roll SAS.

Handling qualities during operational tasks were degraded when the roll and yaw axes were disturbed by a control input or gust. All four configurations suffered from an annoying, poorly damped, "snakey" Dutch roll. The aircraft tended to wander in yaw and precision of the operational tasks suffered. This was especially uncomfortable when very close to the ground during the landing maneuver. However, a technique of using small, slow rolls to level the wings was effective in minimizing the Dutch roll. Because of the annoying Dutch roll, precise turns were largely impractical.

<u>Recommendation 2.</u> Flight in crosswinds and gusts should be avoided due to the natural excitation of an annoying Dutch roll mode. (Page 26)

<u>Recommendation 3.</u> Landings of the 2003 Wright Flyer should be planned in a wide area to avoid the need for large roll control inputs. Roll inputs should be small and only as required to level the wings. (Page 26)

Handling qualities with pitch SAS off, roll SAS off, and WRI off were unsatisfactory for level, non-maneuvering flight and landings. In addition to having the poorest handling qualities, this configuration also resulted in the highest pilot workload. Undesirable motions in pitch and yaw were easily induced and yaw PIO tendencies were apparent. Controlling both the pitch and roll axes simultaneously resulted in a very high workload, and it was easy to become task saturated while controlling the undesirable motion in one axis and forgetting about the other axis. Only one of three pilots was able to land with this configuration by using a constant yaw "dithering" technique. The other

two pilots used a more reactionary technique of keeping a tightly closed loop for detecting small errors in pitch or yaw and correcting them with equally small control inputs. However, both of these pilots experienced situations with small errors and inputs in the pitch and yaw axes, and then in an instant, the errors and inputs grew and a PIO rapidly developed. The test team determined that flying the 2003 Wright Flyer without WRI and without pitch SAS would be impractical and unwise.

As a final note, the use of a ground-based simulator was effective for flight crew preparation prior to actual flight. The team felt that ground-based simulation provided valuable insight into basic handling qualities, timing, and workload for the in-flight maneuvers. The handling qualities of the four Wright Flyer configurations were significantly different from handling qualities of modern aircraft. Flying techniques successfully employed on other airplanes were not necessarily appropriate for the Wright Flyer configurations. Since the actual 2003 Wright Flyer will not have a safety system to "disengage the simulation" nor have a safety pilot aboard, preparation on the ground will be vitally important.

Recommendation 4. A ground-based simulator should be used in preparation for the first flight of the 2003 Wright Flyer. **(Page 27)**

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3. Variable Stability Learjet 24D Pilot Operating Manual, TM-056-LJ1-0029, Veridian Flight Research Group, Veridian Engineering, Buffalo, NY

4. Learjet 24-218 AFM Supplement, Variable Stability System (VSS), TM-056-LJ1-0063, Veridian Flight Research Group, Veridian Engineering, Buffalo, NY, August, 1998

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APPENDIX A – KEY HAVE WRIGHT PERSONNEL

Name	Duties	Organization
Capt Jim Colebank	Project Manager, Flight Test Engineer, Test Conductor	TPS Class 00B
Maj Mike Jansen	Evaluation Pilot, Safety Officer	TPS Class 00B
Capt Kent Johansen	Evaluation Pilot, Budget Officer	TPS Class 00B
Capt Rob Haug	Evaluation Pilot, Scheduling Officer	TPS Class 00B
Capt Tim Jorris	Flight Test Engineer, Test Conductor, TPS Ground Simulator Programmer	TPS Class 00B
Lt Jose Casado	Flight Test Engineer, Test Conductor	TPS Class 00B
Maj Mike Phillips	TPS Staff Advisor	TPS/ED
Mike Nelson	Technical Advisor	TPS/XP
Paul Deppe	VVSLIS Aircraft Commander, Safety Pilot	Veridian Engineering
Dr. Fred Culick	Customer Representative	California Institute of Technology, AIAA
Henry Jex	Customer Representative	AIAA
Andy Markofski	Simulation Engineer, VVSLIS Programmer	Veridian Engineering
Mark Dickerson	Operations Advisor	Veridian Engineering
Doyle Janzen	Technical Chairman	412 TW/TSFB
Dave Warner	Safety Chairman	AFFTC/SET

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APPENDIX B – 2003 WRIGHT FLYER MATH MODEL

Dimensional Aerodynamic Model:

Trim Conditions:

Parameter	Description	Value	Units
Hp	Pressure altitude	0	Feet
Vc	Calibrated airspeed	26	Knots
Flaps	Flaps position	0.0	Degrees
Gross Weight	Gross Weight	750	Lbs
CG	Center of gravity	30	% of Mean Aerodynamic Chord
Ixx	X-Moment of Inertia	2103	Slug*Feet^2
Iyy	Y-Moment of Inertia	290	Slug*Feet^2
Izz	Z-Moment of Inertia	1352	Slug*Feet^2
Ixz	XZ-Product of Inertia	0	Slug*Feet^2
Alpha	Angle of attack	0.0	Degrees
Theta	Pitch angle	0.0	Degrees
Beta	Sideslip	0.0	Degrees
Canard trim position	Canard trim position	5.0	Degrees
Qbar	Dynamic pressure	2.3	Lbs/Feet^2
Ve	Equivalent airspeed	26.1	Knots
Vt	True airspeed	26.1	Knots
Mach	Mach number	0.040	Non-dimensional

Longitudinal dimensional derivatives (Body axis):

Parameter	Description	Value	Units
Xu	X-acceleration due to longitudinal speed	-0.3865	1/sec
Xw	X-acceleration due to vertical speed	0.3087	1/sec
Xwd	X-acceleration due to vertical speed rate	0.0	No-dimensional
Xq	X-acceleration due to pitch rate	0.0	Feet/(rad*sec)
Xdc	X-acceleration due to canard deflection	-3.492	Feet/(rad*sec^2)
Zu	Z-acceleration due to longitudinal speed	-1.4647	1/sec
Zw	Z-acceleration due to vertical speed	-4.625	1/sec
Zwd	Z-acceleration due to vertical speed rate	-0.2808	No-dimensional
Zq	Z-acceleration due to pitch rate	0.0	Feet/(rad*sec)
Zdc	Z-acceleration due to canard deflection	-16.448	Feet/(rad*sec^2)
Mu	Pitch acceleration due to longitudinal speed	0.03415	1/(Feet*sec)
Mw	Pitch acceleration due to vertical speed	0.539197	1/(Feet*sec)
Mwd	Pitch acceleration due to vertical speed rate	0.019648	1/Feet
Mq	Pitch acceleration due to pitch rate	-5.958	No-dimensional
Mdc	Pitch acceleration due to canard deflection	17.94	Rad/(rad*sec^2)

APPENDIX B – 2003 WRIGHT FLYER MATH MODEL (CONT'D)

Longitudinal Model (State-Space, Stability Axis, about trim conditions):

$$\begin{Bmatrix} \dot{Q} \\ \dot{V} \\ \dot{\alpha} \\ \dot{\theta} \end{Bmatrix} = A^* \begin{Bmatrix} Q \\ V \\ \alpha \\ \theta \end{Bmatrix} + B^*\delta_c$$

$$A = \begin{bmatrix} -5.2815 & 0.0117 & 20.6497 & 0.0 \\ 0.0 & -0.3865 & 13.6137 & -32.1720 \\ 0.7808 & -0.0259 & -3.6110 & 0.0 \\ 1.0 & 0.0 & 0.0 & 0.0 \end{bmatrix}; \quad B = \begin{bmatrix} 17.6877 \\ -3.4920 \\ -0.2912 \\ 0.0 \end{bmatrix}$$

Longitudinal model parameters:

Parameter	Description	Units
Q	Pitch rate	rad/sec
V	Flight path velocity	feet/sec
α	Angle of attack	rad
θ	Pitch angle	rad
$\dot{Q}$	Pitch acceleration	rad/sec^2
$\dot{V}$	Flight path velocity rate	feet/sec^2
$\dot{\alpha}$	Angle of attack rate	rad/sec
$\dot{\theta}$	Pitch rate	rad/sec
δ_c	Canard deflection	rad

Lateral dimensional derivatives (Body axis):

Parameter	Description	Value	Units
Yv	Side acceleration due to lateral speed	-0.3615	1/sec
Yb	Side acceleration due to sideslip	44.1*Yv	feet/sec^2
Yp	Side acceleration due to roll rate	0.0	feet/sec
Yr	Side acceleration due to yaw rate	0.0	feet/sec
Ydw	Side acceleration due to delta wing warp	-33.65	feet/sec^2
Ydr	Side acceleration due to delta rudder	12.753	feet/sec^2
Lb	Roll acceleration due to sideslip	0.6465	1/sec^2
Lv	Roll acceleration due to lateral speed	Lb/44.1	1/sec^2
Lp	Roll acceleration due to roll rate	-4.083	1/sec
Lr	Roll acceleration due to yaw rate	1.7159	1/sec
Ldw	Roll acceleration due to delta wing warp	-2.525	1/sec^2
Ldr	Roll acceleration due to delta rudder	0.0633	1/sec^2
Nb	Yaw acceleration due to sideslip	1.1674	1/sec^2
Nv	Yaw acceleration due to lateral speed	Nb/44.1	1/sec^2
Np	Yaw acceleration due to roll rate	-0.3537	1/sec
Nr	Yaw acceleration due to yaw rate	-0.7878	1/sec
Ndw	Yaw acceleration due to delta wing warp	0.8439	1/sec^2
Ndr	Yaw acceleration due to delta rudder	-0.7173	1/sec^2

APPENDIX B – 2003 WRIGHT FLYER MATH MODEL (CONT'D)

Lateral Model (State-Space, Stability Axis, about trim conditions):

$$\begin{Bmatrix} \dot{P} \\ \dot{R} \\ \dot{\beta} \\ \dot{\phi} \end{Bmatrix} = A^* \begin{Bmatrix} P \\ R \\ \beta \\ \phi \end{Bmatrix} + B^* \begin{Bmatrix} \delta_w \\ \delta_r \end{Bmatrix}$$

$$A = \begin{bmatrix} -4.0830 & 1.7159 & 0.6465 & 0.0 \\ -0.3537 & -0.7878 & 1.1674 & 0.0 \\ 0.0 & -1.0 & -0.3615 & 0.7295 \\ 1.0 & 0.0 & 0.0 & 0.0 \end{bmatrix}; \quad B = \begin{bmatrix} -2.5250 & 0.0633 \\ 0.8439 & -0.7173 \\ -0.763 & 0.2892 \\ 0.0 & 0.0 \end{bmatrix}$$

Lateral model parameters:

Parameter	**Description**	**Units**
P	Roll rate	rad/sec
R	Yaw rate	rad/sec
β	Angle of sideslip	rad
ϕ	Bank Angle	rad
$\dot{P}$	Roll acceleration	rad/sec^2
$\dot{R}$	Yaw acceleration	rad/sec^2
$\dot{\beta}$	Angle of sideslip rate	rad/sec
$\dot{\phi}$	Roll rate	rad/sec
δ_w	Wing warp	rad
δ_r	Rudder deflection	rad

APPENDIX B – 2003 WRIGHT FLYER MATH MODEL (CONT'D)

Non-dimensional Aerodynamic Model:

Initial conditions

Parameter	Description	Value	Units
init_V_fps	Initial true airspeed	44.1	feet/sec

Aircraft dimensions and mass properties:

Parameter	Description	Value	Units
wing_area	Wing aerea	510.0	$feet^2$
cbar	Mean Aerodynamic Chord	6.5	feet
b	Wing Span	40.33	feet
cg_ref	CG, Fraction of MAC	0.30	non-dimensional
alpha_ref	AOA at which derivatives are valid	0.0	rad
Vt_ref	True airspeed	44.1	feet/sec
weight	Gross Weight	750.0	lbs
Ixx	X-Moment of Inertia	2103.0	$slug*feet^2$
Iyy	Y-Moment of Inertia	290.0	$slug*feet^2$
Izz	Z-Moment of Inertia	1352.0	$slug*feet^2$
Ixz	XZ-Product of Inertia	0.0	$slug*feet^2$

Non-dimensional lift coefficients

Parameter	Description	Value	Units
CL0	Lift coefficient at 0 angle of attack	0.639	non-dimensional
CLalpha	Lift coefficient due to angle of attack	3.91	1/rad
CLq	Lift coefficient due to pitch rate	0.0	1/rad
CLalpha_dot	Lift coefficient due to angle of attack rate	3.32	1/(rad/sec)
CLdelta_c	Lift coefficient due to canard deflection	0.325	1/rad

Non-dimensional pitching coefficients

Parameter	Description	Value	Units
Cm0	Pitch moment coefficient at 0 angle of attack	0.0	non-dimensional
Cmalpha	Pitch stability	0.9	1/rad
Cmq	Pitch damping	-3.06	1/(rad/sec)
Cmalpha_dot	Pitch moment coefficient due to angle of attack rate	0.445	1/(rad/sec)
Cmdelta_c	Pitch moment coefficient due to canard deflection	0.679	1/rad

Non-dimensional drag coefficients

Parameter	Description	Value	Units
CD0	Drag coefficient at 0 angle of attack	0.12	non-dimensional
CDalpha	Drag coefficient due to angle of attack	0.37	1/(rad/sec)
CDq	Drag coefficient due to pitch rate	0.0	1/rad
CDdelta_c	Drag coefficient due to canard deflection	0.069	1/rad

APPENDIX B – 2003 WRIGHT FLYER MATH MODEL (CONT'D)

Non-dimensional sideforce coefficients

Parameter	Description	Value	Units
CY0	Sideforce coefficient at 0 angle of sideslip	0.0	non-dimensional
CYp	Sideforce coefficient due to roll rate	0.0	1/(rad/sec)
CYr	Sideforce coefficient due to yaw rate	0.0	1/(rad/sec)
CYbeta	Sideforce coefficient due to sideslip	-0.3150	1/rad
CYdelta_w	Sideforce coefficient due to wing warp	-0.6650	1/rad
CYdelta_r	Sideforce coefficient due to rudder warp	0.2520	1/rad

Non-dimensional rolling moments coefficients

Parameter	Description	Value	Units
Clp	Roll damping	-0.3950	1/(rad/sec)
Clr	Rolling moment due to yaw rate	0.1660	1/(rad/sec)
Clbeta	Dihedral effect	0.02860	1/rad
Cldelta_w	Wings warp power	-0.1117	1/rad
Cldelta_r	Rolling moment coefficient due to rudder warp	0.0028	1/rad

Non-dimensional yawing moments coefficients

Parameter	Description	Value	Units
Cnp	Yawing moment due to roll rate	-0.022	1/(rad/sec)
Cnr	Yaw damping	-0.049	1/(rad/sec)
Cnbeta	Weather cock effect	0.0332	1/rad
Cndelta_w	Adverse yaw effect	0.024	1/rad
Cndelta_r	Rudder power	-0.0204	1/rad

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APPENDIX C – FLIGHT CONTROL SYSTEM

2003 WRIGHT FLYER SIMULATION CONTROL SCHEMATIC

2003 WRIGHT FLYER SIMULATION CONTROL SURFACE LIMITS AND FEEL SYSTEM MODELS

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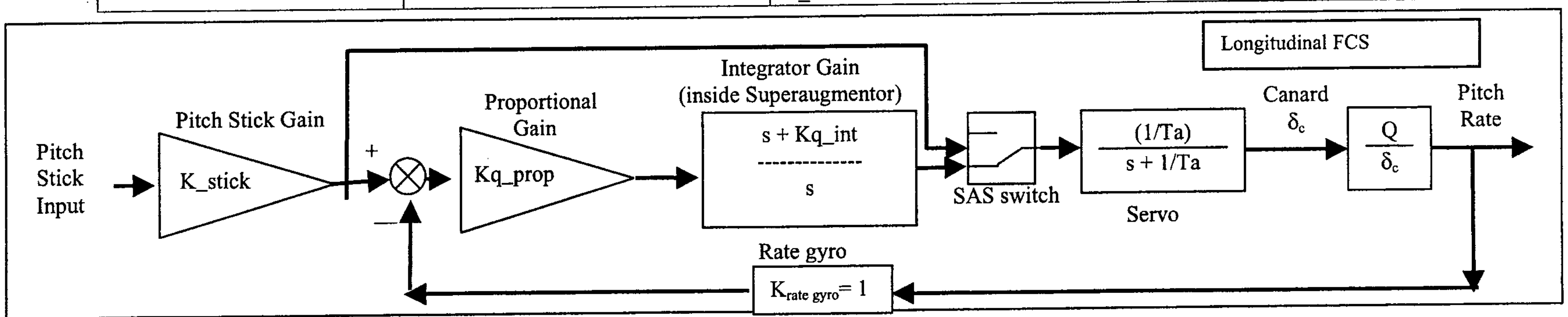
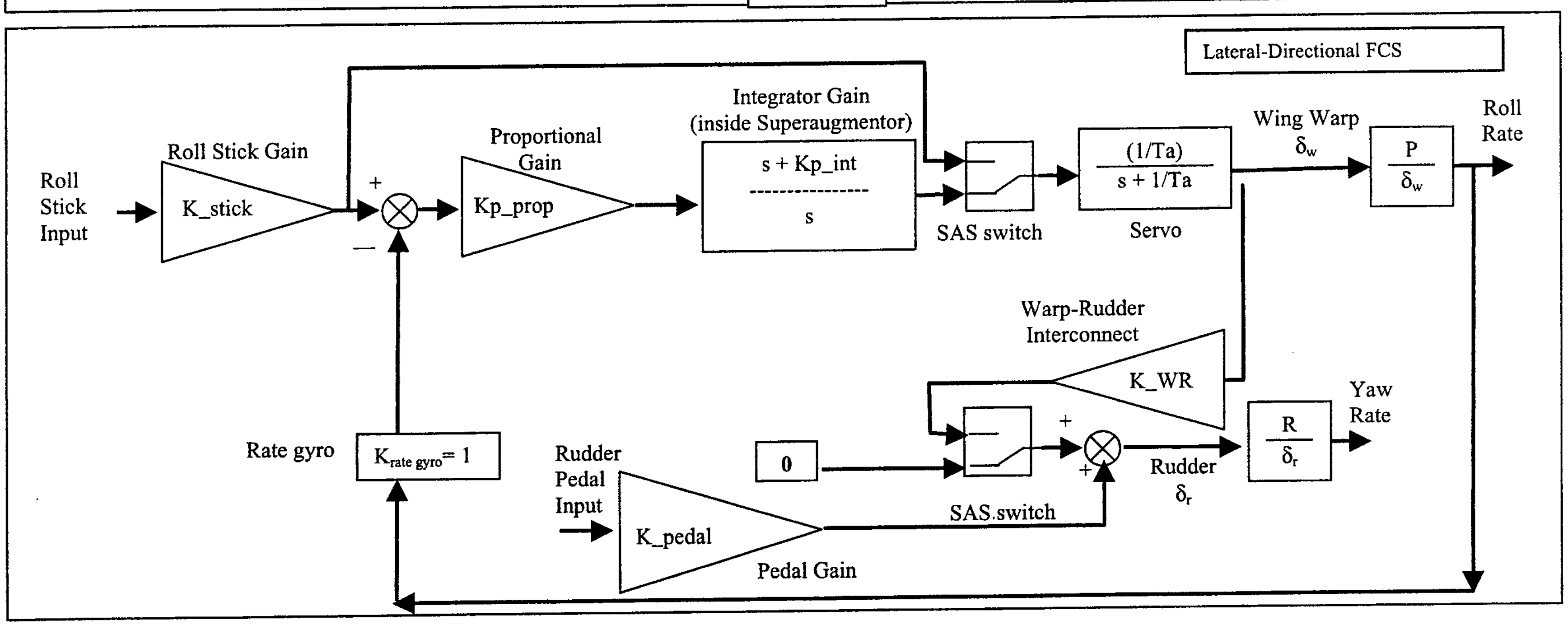
FIGURE C1 – 2003 WRIGHT FLYER SIMULATION CONTROL SCHEMATIC

Servos	Pitch	Roll	Yaw
Ta (servo lag) = 0.025 sec	K_stick = 2.0 deg/inch	K_stick = -4.0 deg/inch	K_pedal = -6.0 deg/inch
	Kq_prop = 0.4 rad/rad/sec	Kp_prop = 1.0 rad/rad/sec	
	Kq_int = 3.5	Kp_int = 3.0	
		K_WR = 1.25	





2003 WRIGHT FLYER SIMULATION CONTROL SURFACE LIMITS AND FEEL SYSTEM MODELS

Control surface limits for in-flight simulation:
Warp: ±20° (positive wing warp deflection causes aircraft to roll left)
Rudder: ±15° (positive rudder deflection causes aircraft to yaw left)
Canard: +12°, -8° (positive canard deflection causes aircraft to pitch up)

Note: The Wright Flyer used wing warp, as opposed to ailerons, for bank control. The VVSLIS aircraft used conventional ailerons to simulate the effect of wing warp. For consistency with the AIAA literature, the HAVE WRIGHT project used the term "warp" to refer to bank control.

Pitch Stick Feel System Model:
Command Gain: 2.0 deg/inch
Stick Deflection Limits: +/- 5 inches (VVSLIS limit for centerstick)
Force Gradient: 6 lb / inch
Preload (Breakout Force): 1 lb
Sign Convention: aft stick force and deflection was positive

Roll Stick Feel System Model:
Command Gain: -4.0 deg/inch
Stick Deflection Limits: +/- 5 inches (VVSLIS limit for centerstick)
Force Gradient: 2.8 lb /inch
Preload (Breakout Force): 0.5 lb
Sign Convention: right stick force and deflection was positive

Rudder Pedal Feel System Model:
Command Gain: -6.0 deg/inch
Pedal Deflection Limits: +/- 2.5 inches (VVSLIS limit)
Force Gradient: 30 lb /inch
Preload (Breakout Force): 4 lb
Sign Convention: right pedal force and deflection was positive

APPENDIX D – VVSLIS INSTRUMENTATION PARAMETER LIST

VVSLIS Aircraft Response and Variable Stability System Information:

Parameter Name	Units	Comment
sys_eng	0 or 1	system_engaged
fes	lb	pitch stick force
fas	lb	roll stick force
frp	lb	rudder pedal force
des	in	pitch stick deflection
das	in	roll stick deflection
drp	in	rudder pedal deflection
ds	deg	Learjet stab deflection
de	deg	Learjet elevator deflection
da	deg	Learjet aileron deflection
dr	deg	Learjet rudder deflection
p	deg/s	Learjet roll rate
q	deg/s	Learjet pitch rate
r	deg/s	Learjet yaw rate
phi	deg	Learjet bank angle
theta	deg	Learjet pitch angle
psi	deg	Learjet heading angle
nx	g	Learjet longitudinal acceleration
ny	g	Learjet lateral acceleration
nz	g	Learjet normal acceleration
nzp	g	Learjet normal acceleration-pilot station
alpha_cf	deg	Learjet complementary-filtered AOA
alphdot_i	deg/s	Learjet AOA rate
beta_cf	deg	Learjet sideslip angle
betadot_i	deg/s	Learjet sideslip angle rate
vi	knots	Learjet indicated airspeed
hp	ft	Learjet pressure altitude
h_cf	ft	Learjet complementary filtered altitude
h_radar	ft	Learjet radar altitude
hdotdot_i	ft/s/s	Learjet hdot rate
hdot_cf	ft/s	Learjet complementary filtered sink rate/climb rate
gamma	deg	Learjet flight path angle
oat	degk	Learjet air temp
thrust_l	lbs	Learjet thrust_left engine
thrust_r	lbs	Learjet thrust_right engine
fuel_cnt	0 or 1	Learjet fuel_counter_pulses
stk_sw	0 or 1	Learjet stick_switches
ap_disc	0 or 1	Learjet autopilot_disconnect button

APPENDIX D – VVSLIS INSTRUMENTATION PARAMETER LIST (CONT'D)

2003 Wright Flyer Model Information Programmed on VVSLIS Aircraft:

Parameter Name	Units	Comment
dec_m	deg	model canard command
de_m	deg	model canard deflection
dec_sas_m	deg	model SAS canard command
dac_m	deg	model wing warp command
da_m	deg	model wing warp deflection
dac_sas_m	deg	model SAS wing warp command
p_sas_on	0 or 1	pitch SAS on or off
r_sas_on	0 or 1	roll SAS on or off
y_sas_on	0 or 1	yaw SAS on or off
dr_m	deg	model rudder deflection
drc_m	deg	model rudder command
drc_sas_m	deg	model warp-rudder command

APPENDIX E – HAVE WRIGHT FLIGHT TEST CONDITION MATRIX

No.	Objective #	Maneuver	Altitude (ft PA)	Airspeed	Config	Target Aircraft	Limitations	Comments
1	2	Low Bandwidth - Level Flight	10,000 ft ± 2,000 ft	145 KIAS ± 5 KIAS	1[2]	N/R[1]	>5,000 ft AGL V_{max} w/gear = 190 KIAS	Gathered pilot comments and filled in Analog Rating Scales (Appendix I)
2	2	Low Bandwidth - Pitch Captures	10,000 ft ± 2,000 ft	145 KIAS ± 5 KIAS	1	N/R	>5,000 ft AGL V_{max} w/gear = 190 KIAS	Pitch captures to ±5° and ±10° Gathered pilot comments and filled in Analog Rating Scales (Appendix I)
3	2	Low Bandwidth - Bank Captures	10,000 ft ± 2,000 ft	145 KIAS ± 5 KIAS	1	N/R	>5,000 ft AGL V_{max} w/gear = 190 KIAS	Bank captures to ±10°,±15°, ±20°, and ±30° Gathered pilot comments and filled in Analog Rating Scales (Appendix I)
4	2	Low Bandwidth - Heading Captures	10,000 ft ± 2,000 ft	145 KIAS ± 5 KIAS	1	N/R	>5,000 ft AGL V_{max} w/gear = 190 KIAS	Heading Captures to ±30° Gathered pilot comments and filled in Analog Rating Scales (Appendix I)
5	2	Low Bandwidth - Steady Heading Sideslips (SHSS)	10,000 ft ± 2,000 ft	145 KIAS ± 5 KIAS	4 only (omit for 1,2,&3)	N/R	>5,000 ft AGL V_{max} w/gear = 190 KIAS	Slowly varying SHSS to full left/right rudder deflection Gathered pilot comments and filled in Analog Rating Scales (Appendix I)

APPENDIX E – HAVE WRIGHT TEST CONDITION MATRIX (CONT'D)

No.	Objective #	Maneuver	Altitude (ft PA)	Airspeed	Config	Target Aircraft	Limitations	Comments
6	2	High Bandwidth - Pitch Pointing	10,000 ft ± 2,000 ft	145 KIAS ± 5 KIAS	1[2]	Required	>5,000 ft AGL 500 ft separation with target V_{max} w/gear = 190 KIAS	Trail position 1,000 ft behind target Performed Handling Qualities During Tracking (HQDT) for 30 seconds. Tracked to zero pitch error by aligning Veridian pipper on the Target. Target was in level flight initially then target alternated between ±5° pull-ups and pushovers at a slow rate. Pilot assigned Pilot In-the-loop Oscillation Rating (PIOR)
7	2	High Bandwidth - Bank Matching	10,000 ft ± 2,000 ft	145 KIAS ± 5 KIAS	1	Required	>5,000 ft AGL 500 ft separation with target V_{max} w/gear = 190 KIAS	Trail position 1,000 ft behind target Performed HQDT for 30 seconds. Tracked to zero error by matching aircraft bank angle to Target bank angle. Target alternated between ±10° rolls at a slow rate. Pilot assigned PIOR
8	2	High Bandwidth - Pitch Attitude Tracking	10,000 ft ± 2,000 ft	145 KIAS ± 5 KIAS	1	Required	>5,000 ft AGL Nose-tail clearance w/ target V_{max} w/gear = 190 KIAS	3 to 4 wingspan route position with nose-tail clearance maintained Performed pitch attitude HQDT for 30 seconds. Tracked to zero error by tracking target while target held 5° nose down dive. Pilot assigned PIOR
9	2	High Bandwidth - Simulated Flare	10,000 ft ± 2,000 ft	145 KIAS ± 5 KIAS	1	Required	>5,000 ft AGL Nose-tail clearance w/ target V_{max} w/gear = 190 KIAS	Setup 3 to 4 wingspan route position with nose-tail clearance maintained Climb ≈50 ft above Target altitude, descend and simulate landing flare using Target as a visual reference. Pilot assigned PIOR

APPENDIX E – HAVE WRIGHT TEST CONDITION MATRIX (CONT'D)

No.	Objective #	Maneuver	Altitude (ft PA)	Airspeed	Config	Target Aircraft	Limitations	Comments
10-18	2	Same as No. 1-9			2[2]	Same as No. 1-9		Same as No. 1-9
19-27	2	Same as No. 1-9			3	Same as No. 1-9		
28-36	2	Same as No. 1-9			4	Same as No. 1-9		
37	3	100 ft AGL low altitude flight	≈100 ft AGL	145 KIAS ± 5 KIAS	1[3]	N/R	> 50 ft AGL V_{max} w/gear = 190 KIAS	Used tower flyby line for known visual references Desired criteria: Hold level flight for at least 30 sec Adequate criteria: Hold level flight for at least 15 sec Pilot assigned Cooper-Harper Rating (CHR) and PIOR
38	3	Sustained level flight over the runway (20 feet AGL goal)	≈20 ft AGL	145 KIAS ± 5 KIAS	1[3]	N/R	V_{max} w/gear = 190 KIAS	Desired criteria: Hold level flight for at least 30 sec over runway Adequate criteria: Hold level flight for at least 15 sec over runway Pilot assigned CHR and PIOR
39	3	Landing	Runway	145 KIAS ± 5 KIAS	1[3]	N/R	V_{max} w/gear = 190 KIAS	Straight-in landing from sustained level flight (20 feet AGL goal) over the runway Desired criteria: Softly land within ±500 feet of an aimpoint and ±10 feet of centerline Adequate criteria: firmly (or softly) land within ±1000 feet of an aimpoint and ±20 feet of centerline Pilot assigned CHR and PIOR

APPENDIX E – HAVE WRIGHT TEST CONDITION MATRIX (CONT'D)

No.	Objective #	Maneuver	Altitude (ft PA)	Airspeed	Config	Target Aircraft	Limitations	Comments
40-42	3	Same as 37-39			2[2]			Same as 37-39.
43-45	3				3			
46-48	3				4			

Notes:

1. N/R – not required
2. Configurations:

(1) Pitch SAS OFF	Roll SAS OFF	WRI ON	Flaps 20%	Gear Down
(2) Pitch SAS ON	Roll SAS OFF	WRI ON	Flaps 20%	Gear Down
(3) Pitch SAS ON	Roll SAS ON	WRI ON	Flaps 20%	Gear Down
(4) Pitch SAS OFF	Roll SAS OFF	WRI OFF	Flaps 20%	Gear Down

3. The configuration with the best handling qualities at altitude was the first configuration tested during operational tasks near the ground (No. 37-39).

APPENDIX F – HAVE WRIGHT FLIGHT TEST SORTIE LOG

VVSLIS Aircraft Sorties

Flight #	Date/ Duration	Crew	Flight Duty	Test Points	Comments
1	18 Apr 01 1.5 hrs	Jorris Johansen Deppe Markofski	Test Conductor Evaluation Pilot Safety Pilot Simulation Engineer	Low and high bandwidth evaluation at 10K ft MSL	
2	18 Apr 01 1.6 hrs	Colebank Haug Deppe Markofski	Test Conductor Evaluation Pilot Safety Pilot Simulation Engineer	Low and high bandwidth evaluation at 10K ft MSL	
3	19 Apr 01 1.5 hrs	Casado Jansen Deppe Markofski	Test Conductor Evaluation Pilot Safety Pilot Simulation Engineer	Low and high bandwidth evaluation at 10K ft MSL	
4	19 Apr 01 1.5 hrs	Colebank Johansen Deppe Markofski	Test Conductor Evaluation Pilot Safety Pilot Simulation Engineer	100 ft AGL flight, 20 ft AGL flight, Landings	Light to moderate turbulence, gusty winds (20 knot headwind gusting to 28 knots)
5	20 Apr 01 1.5 hrs	Casado Haug Deppe Markofski	Test Conductor Evaluation Pilot Safety Pilot Simulation Engineer	100 ft AGL flight, 20 ft AGL flight, Landings	Landings at PMD RWY 25 to avoid traffic in EDW pattern, 6 knot crosswind
6	20 Apr 01 1.5 hrs	Jorris Jansen Deppe Markofski	Test Conductor Evaluation Pilot Safety Pilot Simulation Engineer	100 ft AGL flight, 20 ft AGL flight, Landings	Landings at PMD RWY 25 to avoid traffic in EDW pattern, ≈5 knot crosswind

Note: All four configurations of the 2003 Wright Flyer simulation were evaluated on every sortie.

C-12C Huron Target Aircraft Sorties

Flight #	Date / Duration	Crew	Flight Duty
1	18 Apr 01 / 1.6 hrs	Evans Haug	Aircraft Commander Pilot
2	18 Apr 01 / 1.7 hrs	Cooley Johansen	Aircraft Commander Pilot
3	19 Apr 01 / 1.6 hrs	Edwards Haug	Aircraft Commander Pilot

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APPENDIX G - TEST DATA

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Test Aircraft: Learjet 24D In–flight Simulator
Tail# N101VS: Gear Down, Flaps 20%
Task: Sustained Level Flight Over the Runway
Configurations: 1–4 Pilots: A–C

Simulation: 2003 Wright Flyer
Date: 19–20 Apr 01
Altitude: 20 ft AGL
Airspeed: 145 KIAS

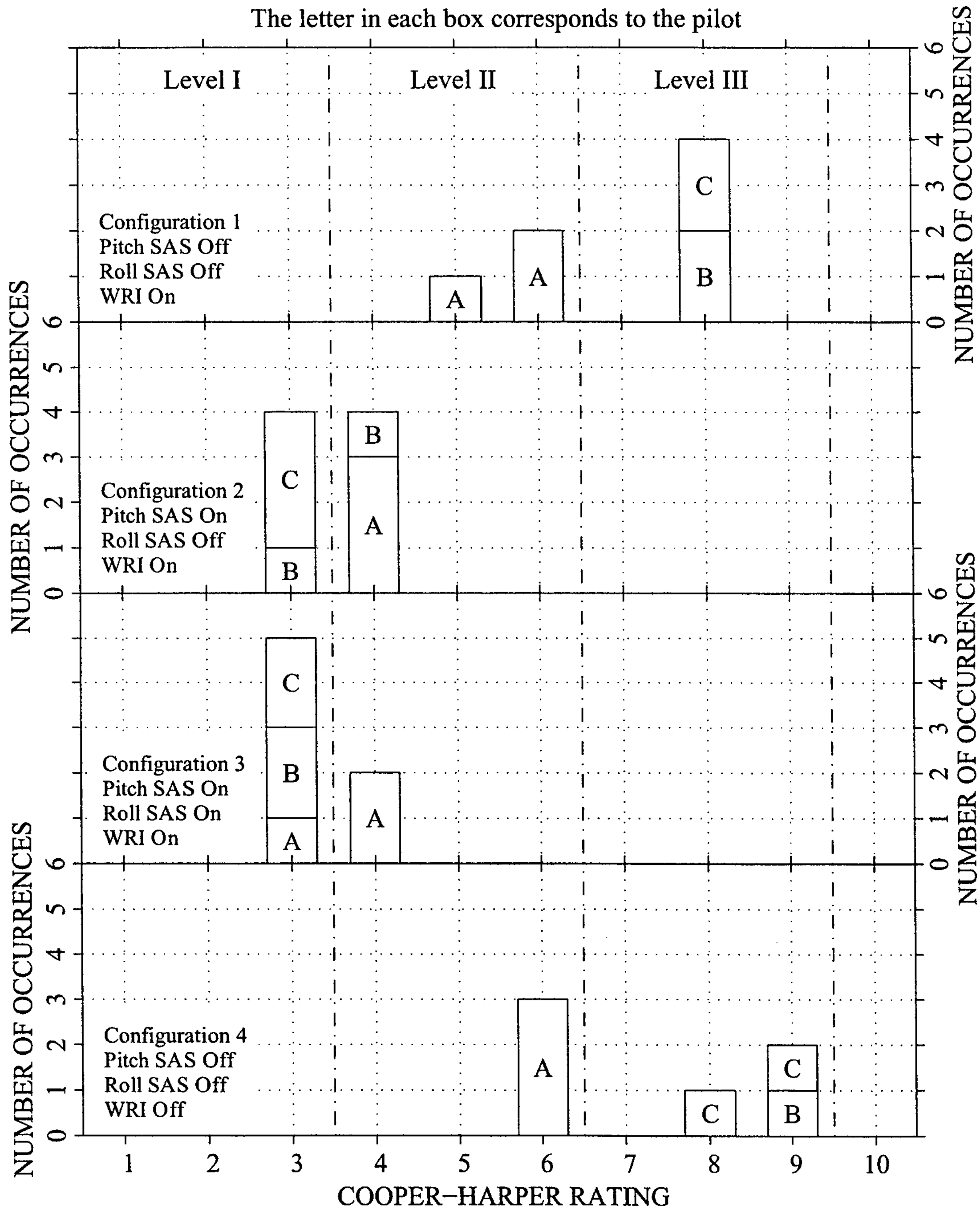

Figure G1 Cooper–Harper Ratings for Sustained Level Flight Over the Runway

Test Aircraft: Learjet 24D In–flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 19–20 Apr 01
Task: Landing	Altitude: Runway
Configurations: 1–4 Pilots: A–C	Airspeed: 145 KIAS

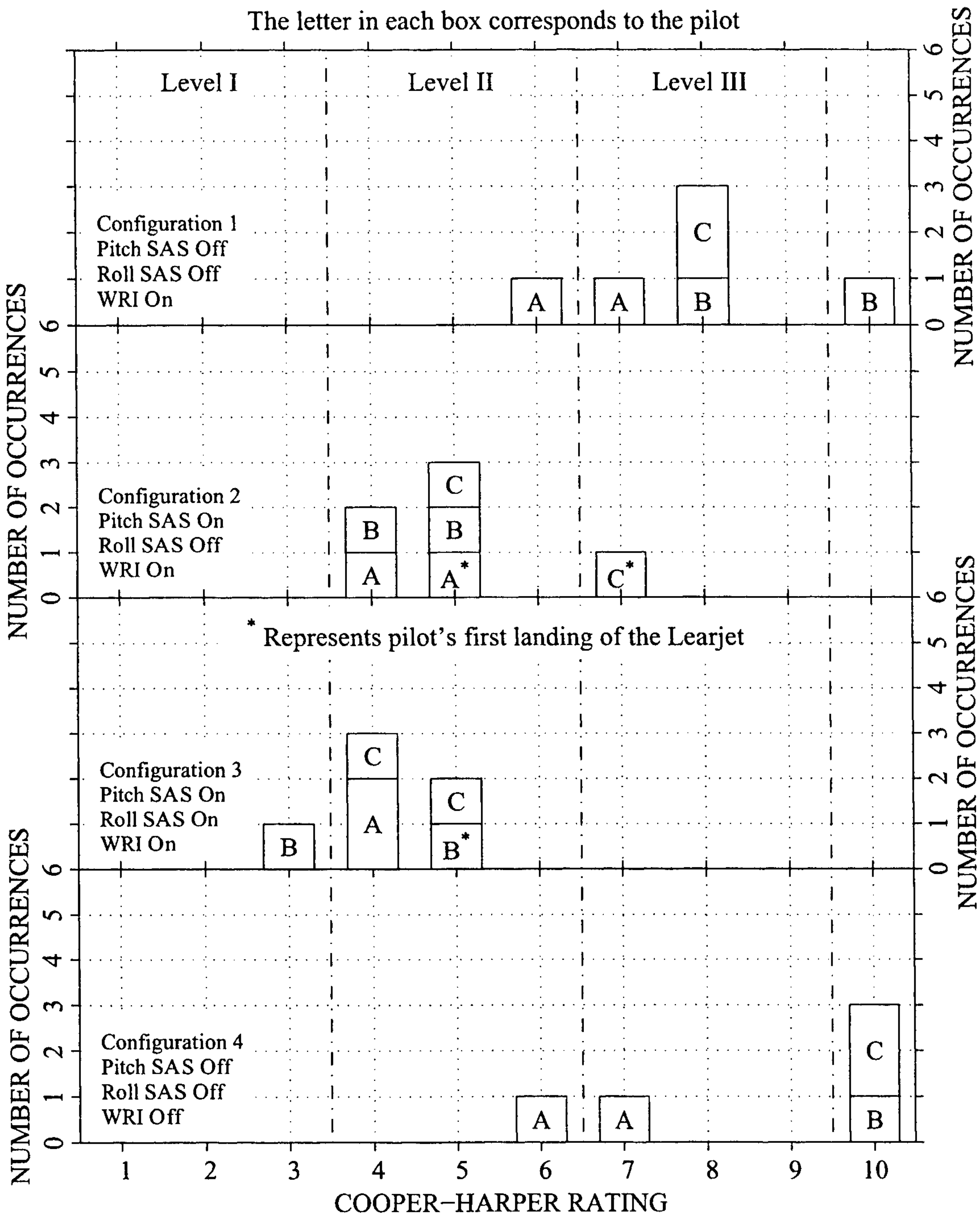

Figure G2 Cooper–Harper Ratings for Landings

Test Aircraft: Learjet 24D In–flight Simulator
Tail# N101VS: Gear Down, Flaps 20%
Task: Sustained Level Flight Over the Runway
Configurations: 1–4 Pilots: A–C

Simulation: 2003 Wright Flyer
Date: 19–20 Apr 01
Altitude: 20 ft AGL
Airspeed: 145 KIAS

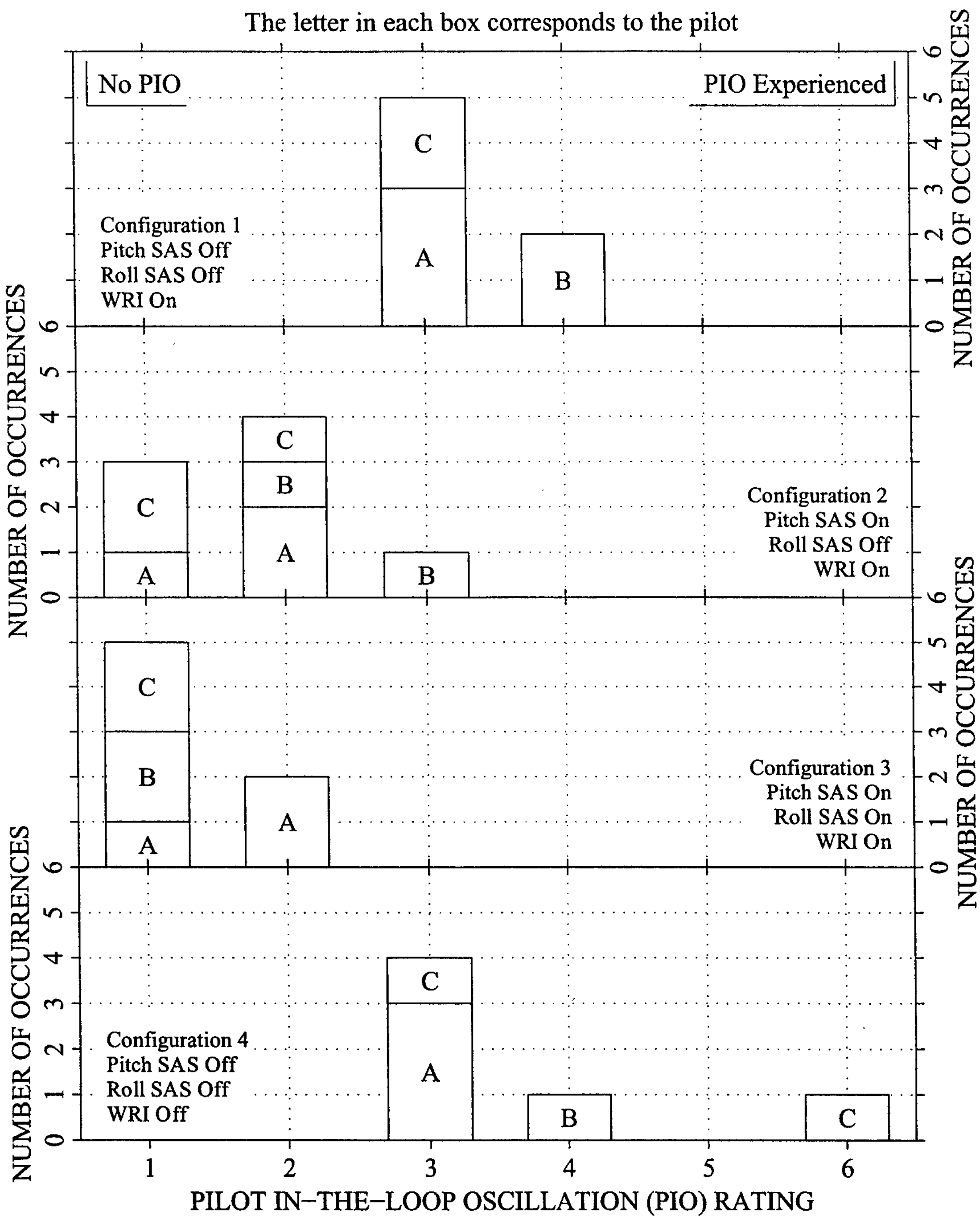

Figure G3 Pilot In–the–Loop Oscillation (PIO) Ratings for Sustained Level Flight Over the Runway

Test Aircraft: Learjet 24D In-flight Simulator
Tail# N101VS: Gear Down, Flaps 20%
Task: Landing
Configurations: 1–4 Pilots: A–C

Simulation: 2003 Wright Flyer
Date: 19–20 Apr 01
Altitude: Runway
Airspeed: 145 KIAS

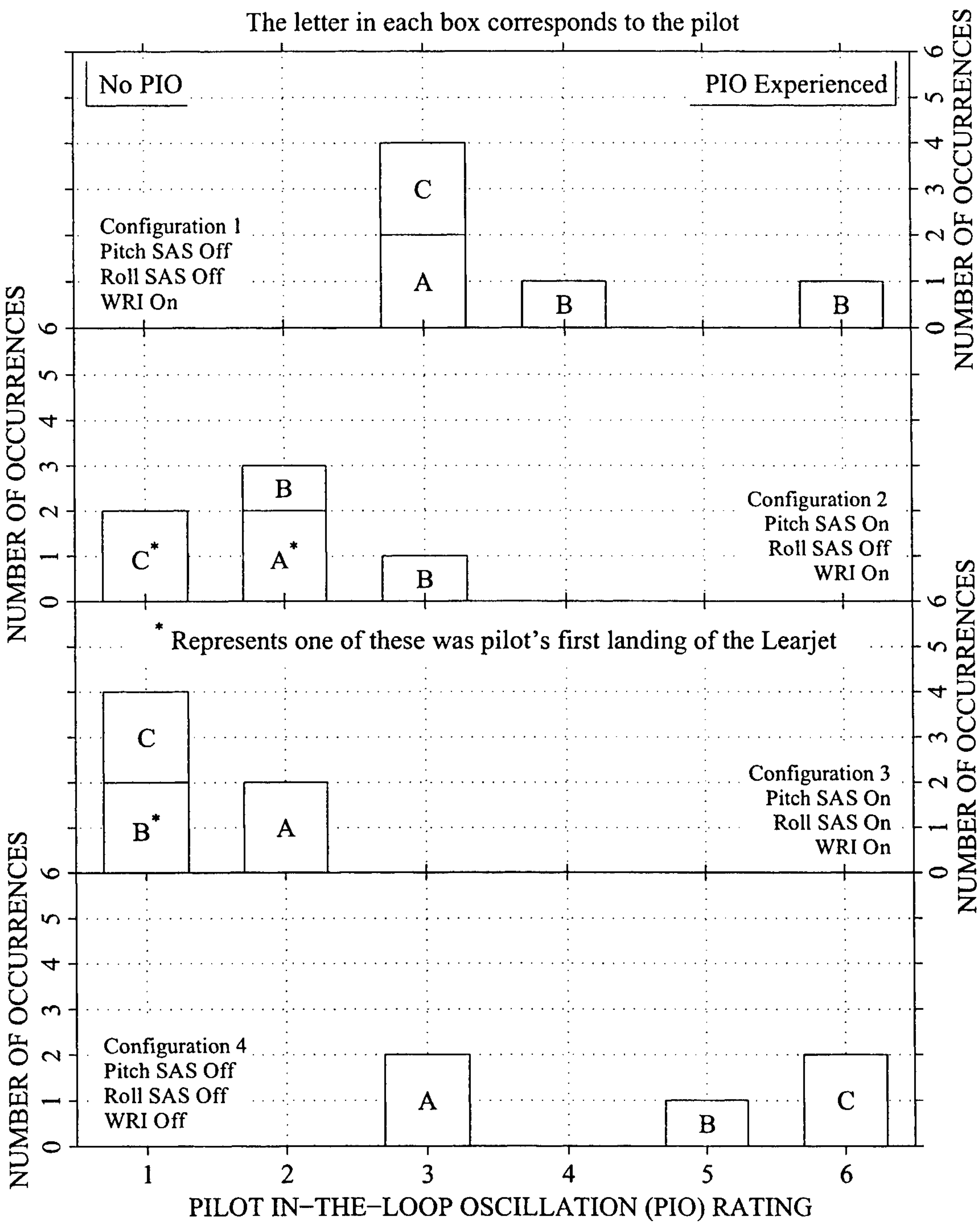

Figure G4 Pilot In–the–Loop Oscillation (PIO) Ratings for Landings

Test Aircraft: Learjet 24D In–flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 20 Apr 01
Task: Level Flight and Landing	Altitude: 20 feet AGL – Runway
Configurations: 1–4 Pilot: A	Airspeed: 145 KIAS

Time slice is last 30 seconds of flight

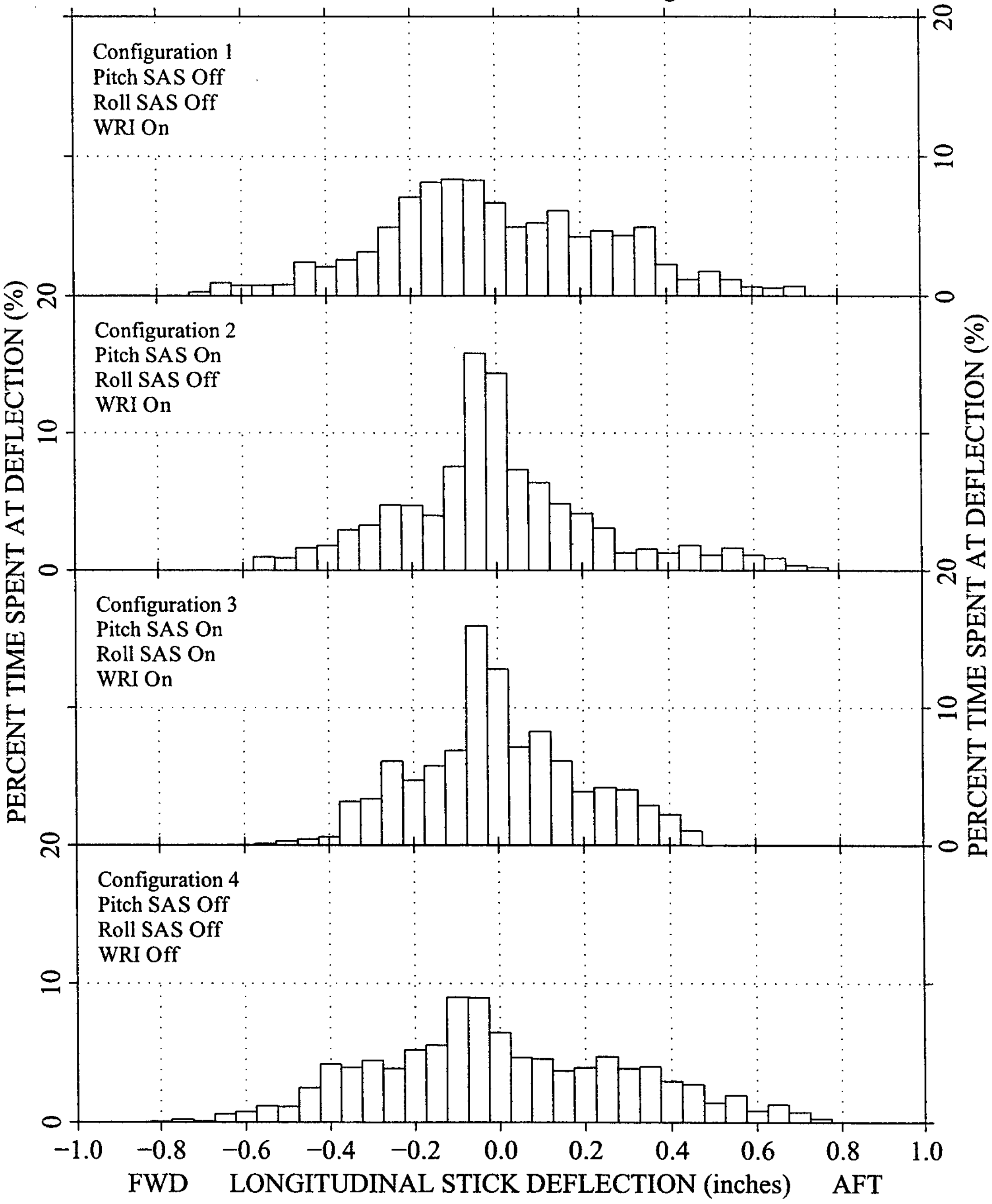

Figure G5 Pilot A Longitudinal Stick Deflection Histograms

Test Aircraft: Learjet 24D In–flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 19 Apr 01
Task: Level Flight and Landing	Altitude: 20 feet AGL – Runway
Configurations: 1–4 Pilot: B	Airspeed: 145 KIAS

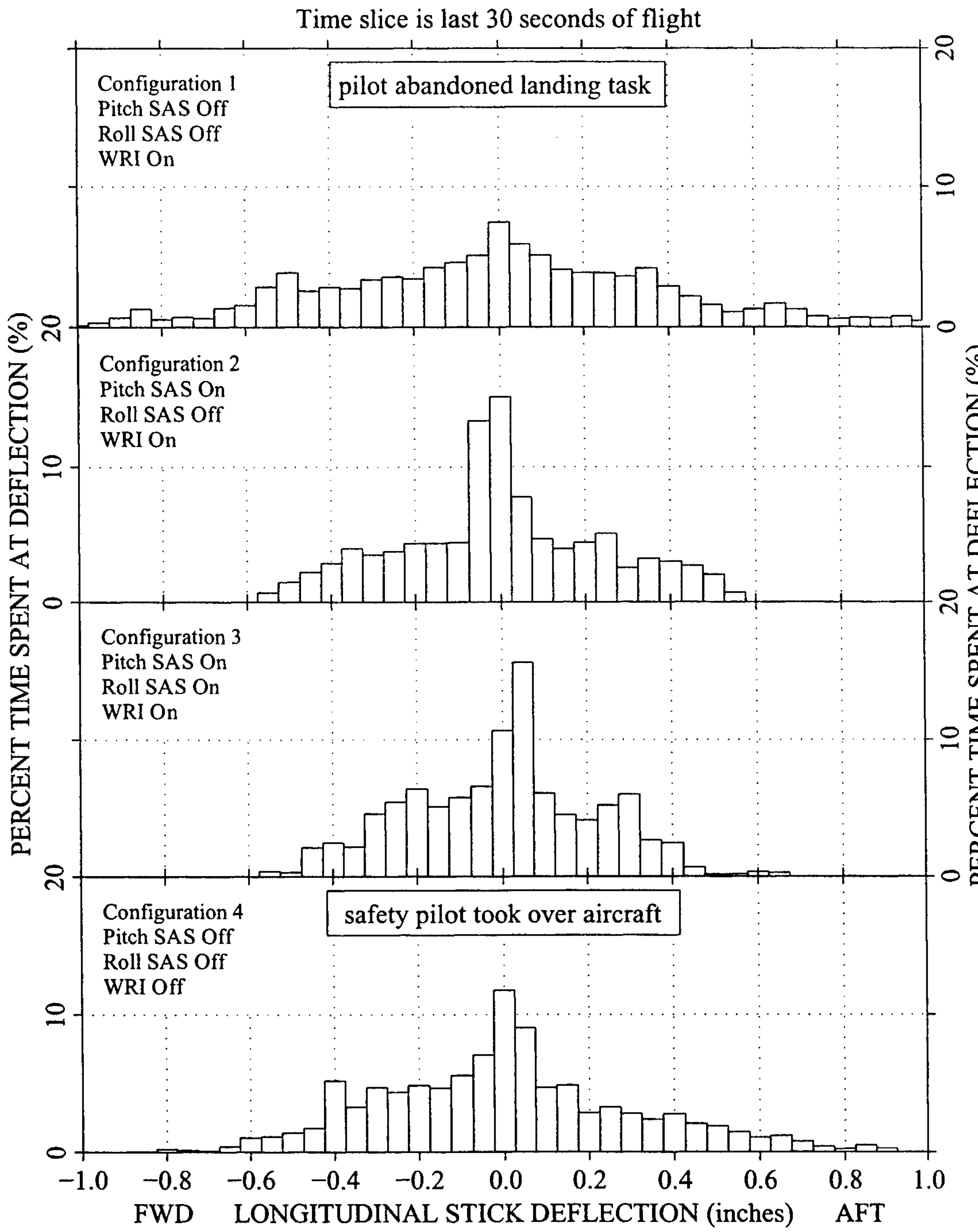

Figure G6 Pilot B Longitudinal Stick Deflection Histograms

Test Aircraft: Learjet 24D In−flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 20 Apr 01
Task: Level Flight and Landing	Altitude: 20 feet AGL − Runway
Configurations: 1−4 Pilot: C	Airspeed: 145 KIAS

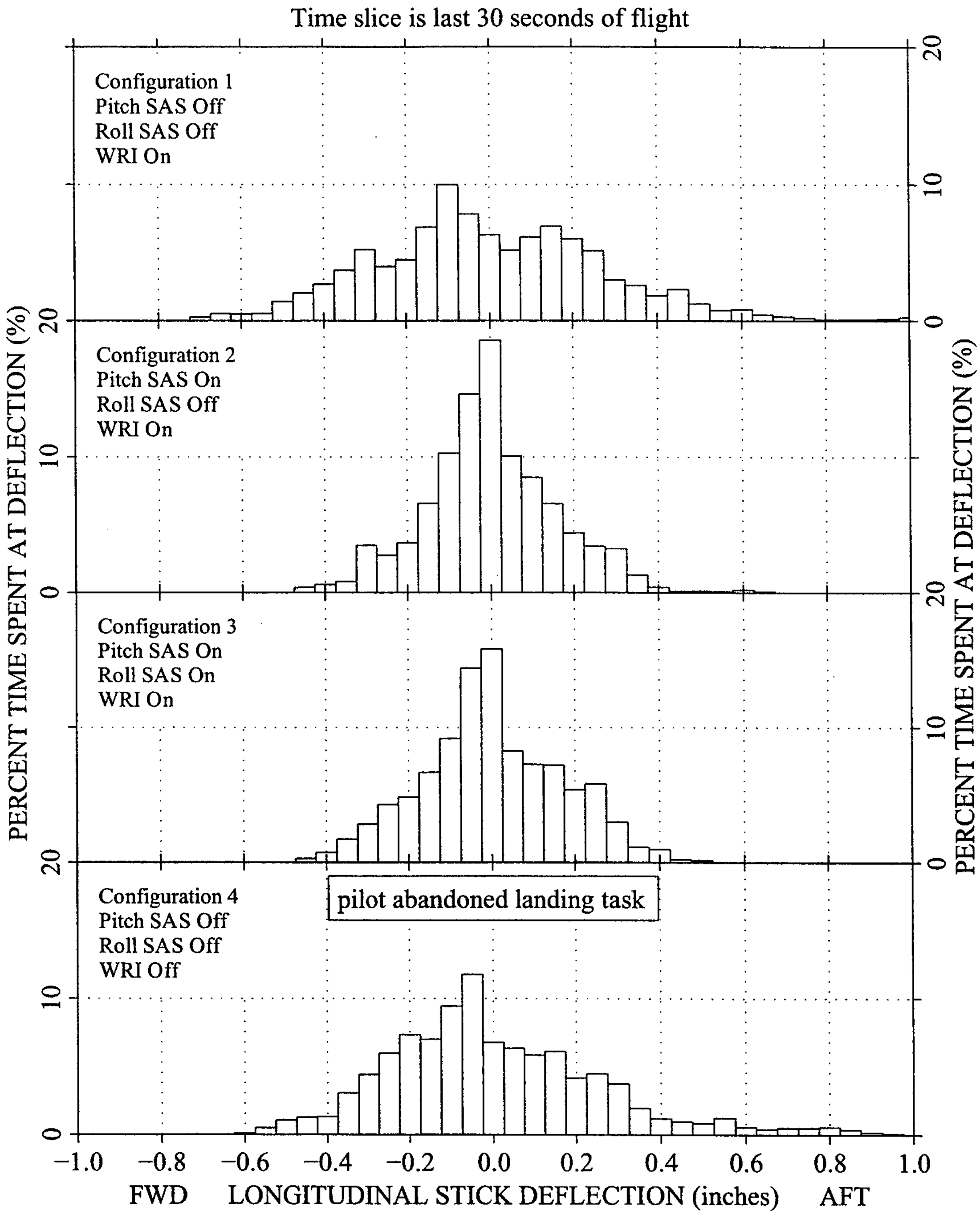

Figure G7 Pilot C Longitudinal Stick Deflection Histograms

Test Aircraft: Learjet 24D In−flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 20 Apr 01
Task: Level Flight and Landing	Altitude: 20 feet AGL − Runway
Configurations: 1−4 Pilot: A	Airspeed: 145 KIAS

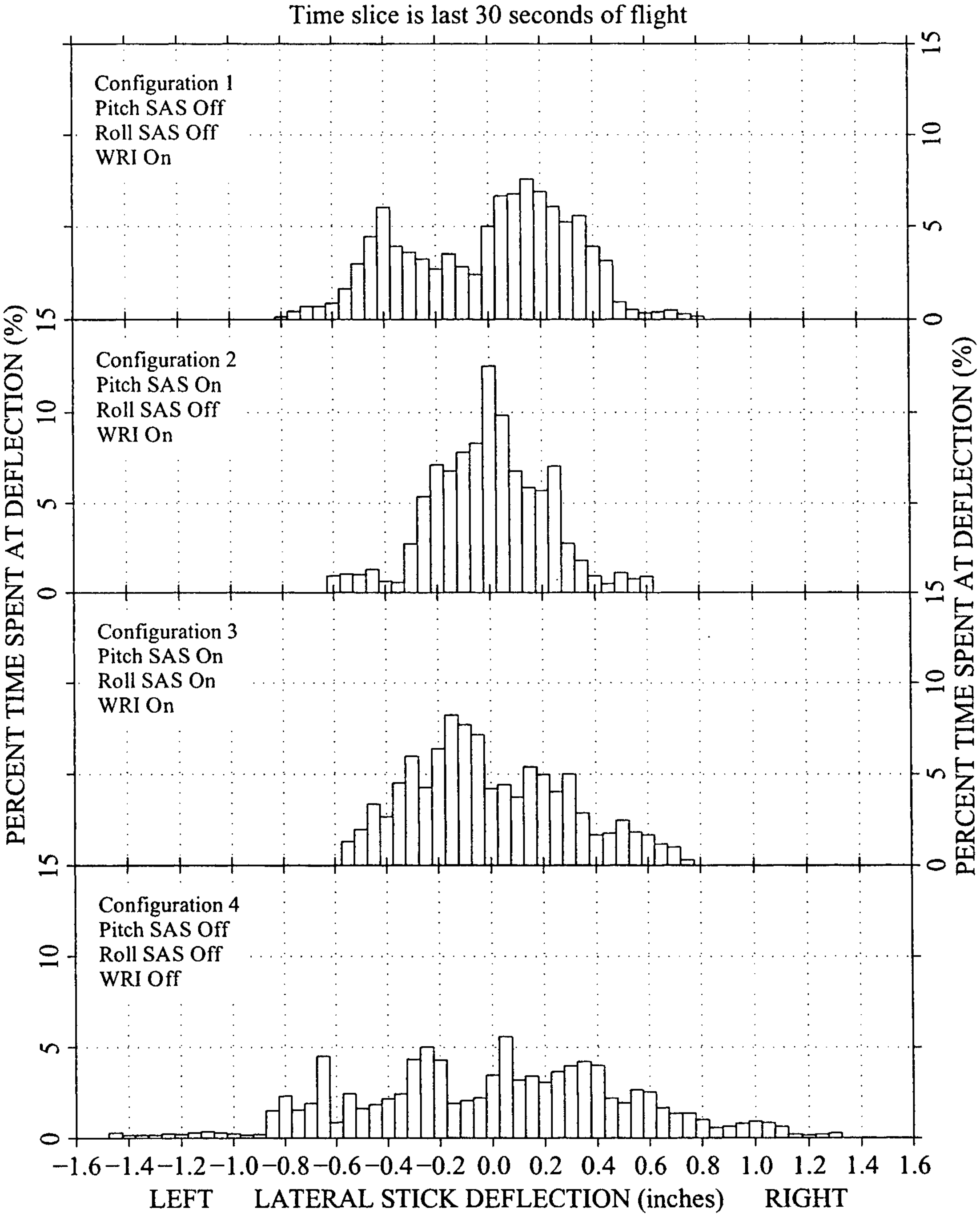

Figure G8 Pilot A Lateral Stick Deflection Histograms

Test Aircraft: Learjet 24D In–flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 19 Apr 01
Task: Level Flight and Landing	Altitude: 20 feet AGL – Runway
Configurations: 1–4 Pilot: B	Airspeed: 145 KIAS

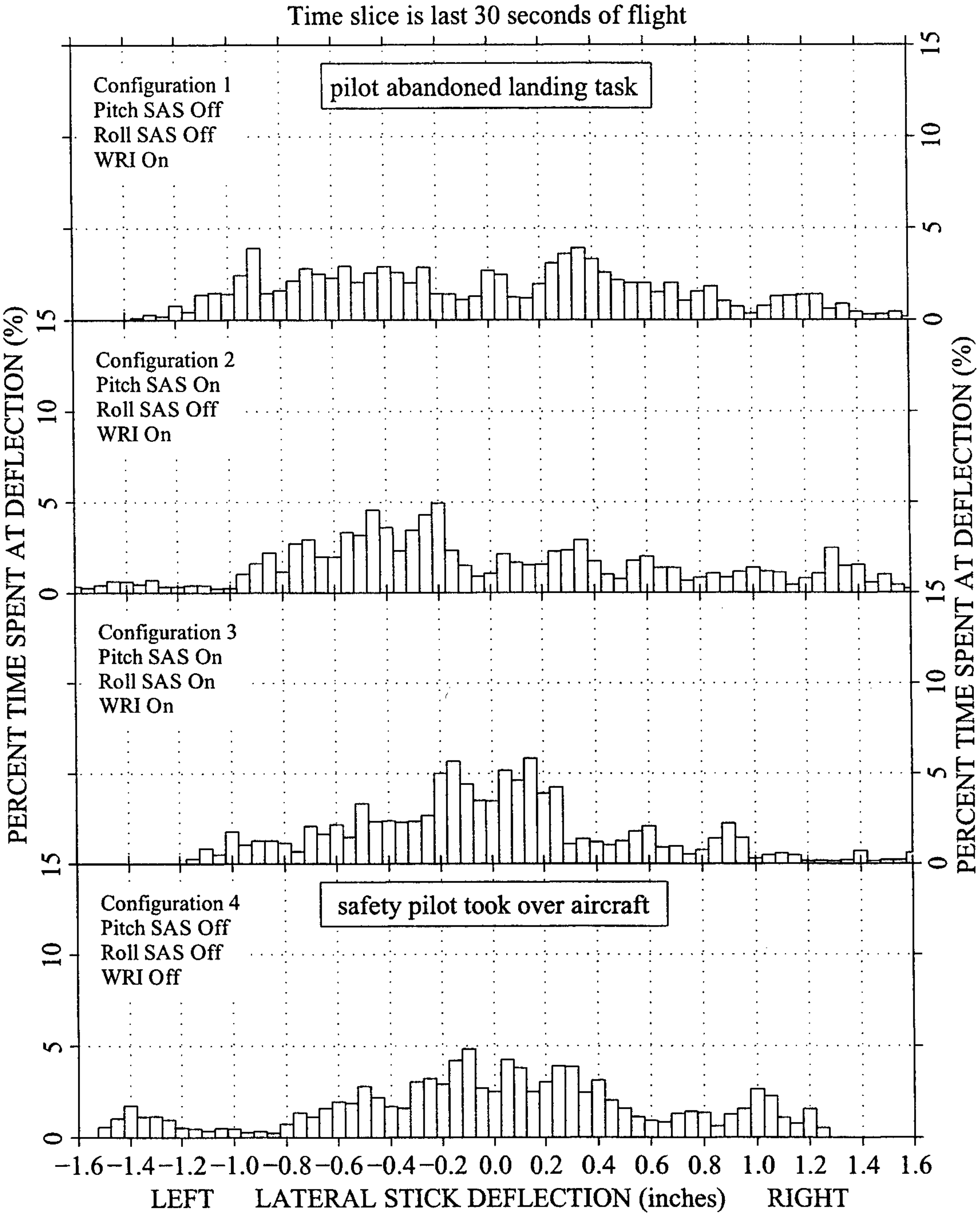

Figure G9 Pilot B Lateral Stick Deflection Histograms

Test Aircraft: Learjet 24D In–flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 20 Apr 01
Task: Level Flight and Landing	Altitude: 20 feet AGL – Runway
Configurations: 1–4 Pilot: C	Airspeed: 145 KIAS

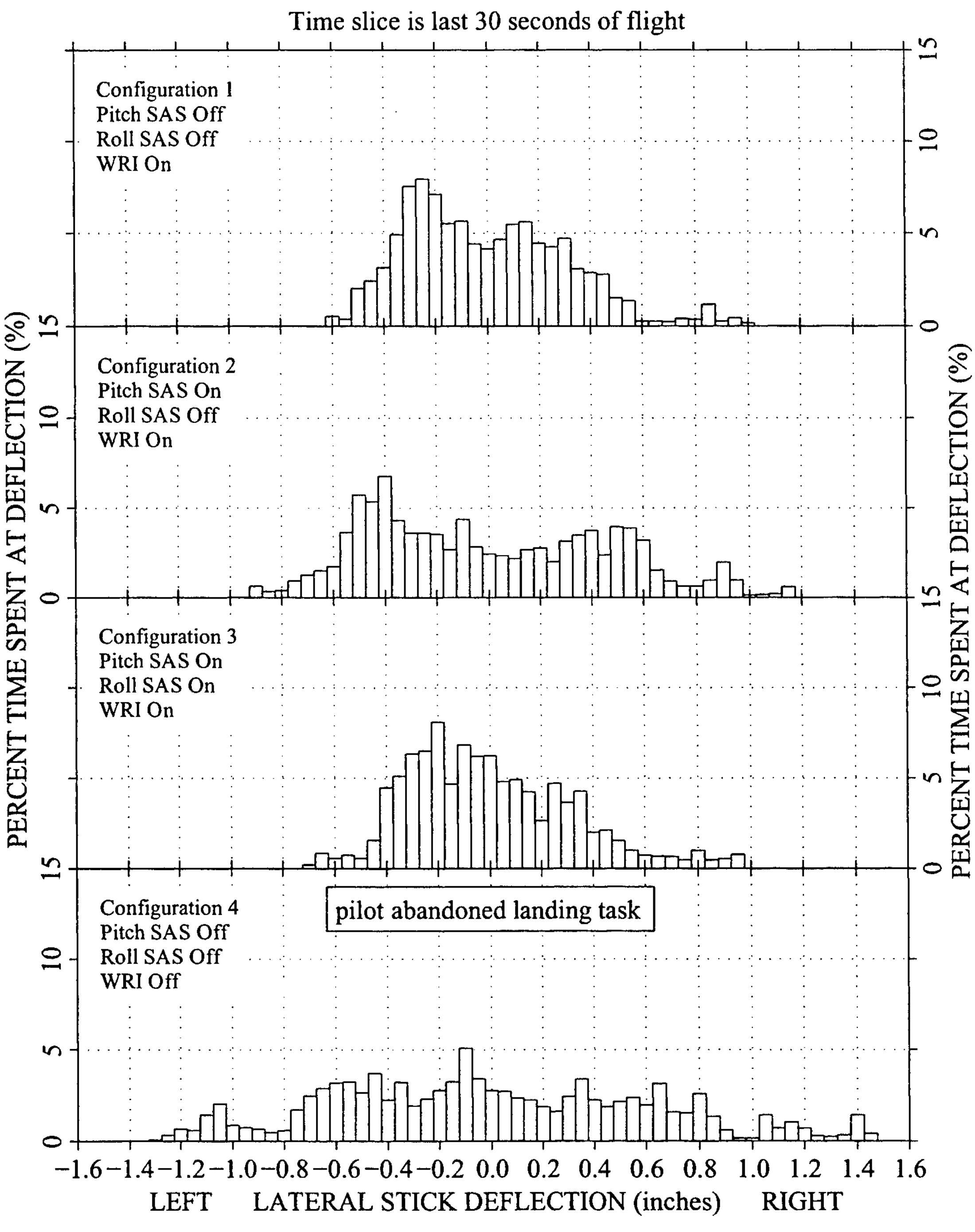

Figure G10 Pilot C Lateral Stick Deflection Histograms

Test Aircraft: Learjet 24D In–flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 19–20 Apr 01
Task: Level Flight and Landing	Altitude: 20 feet AGL – Runway
Configuration: 4 Pilot: A–C	Airspeed: 145 KIAS

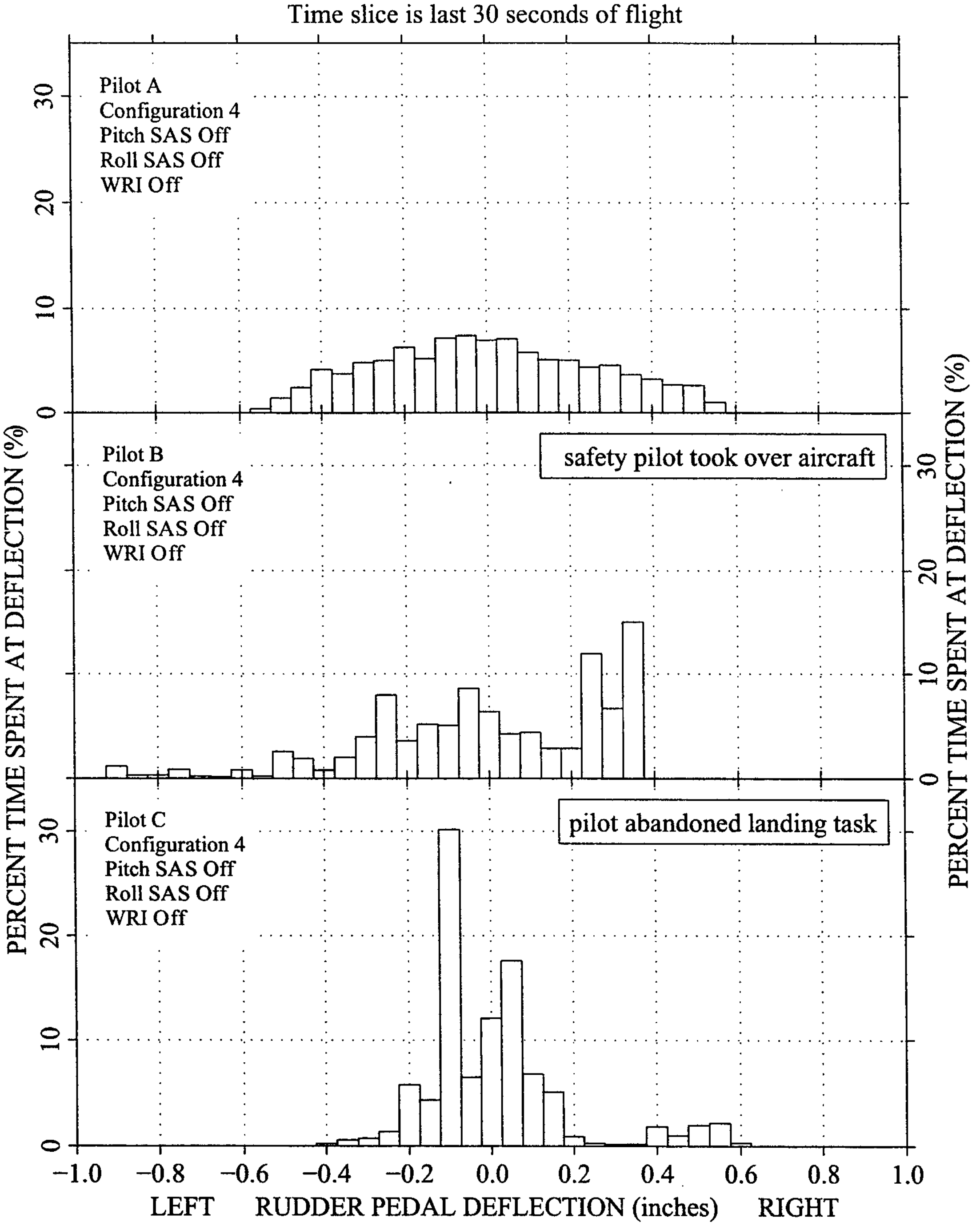

Figure G11 Pilots A–C Rudder Pedal Deflection Histograms

Test Aircraft: Learjet 24D In–flight Simulator
Tail# N101VS: Gear Down, Flaps 20%
Task: Level Flight and Landing
Configurations: 1 and 2 Pilot: A

Simulation: 2003 Wright Flyer
Date: 20 Apr 01
Altitude: 20 ft AGL – Runway
Airspeed: 145 KIAS

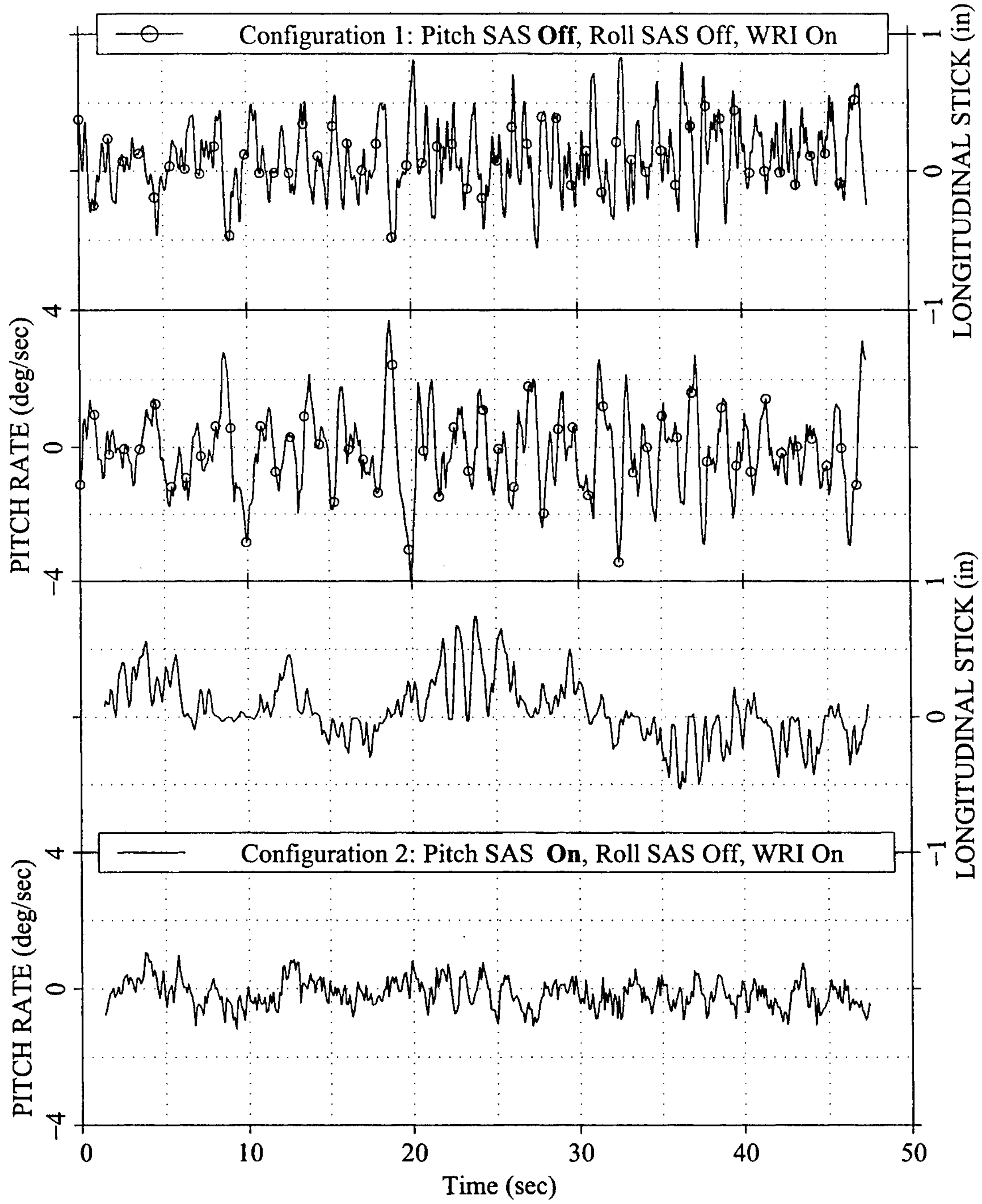

Figure G12 Pilot A Time History of Landing with Pitch SAS Off and On

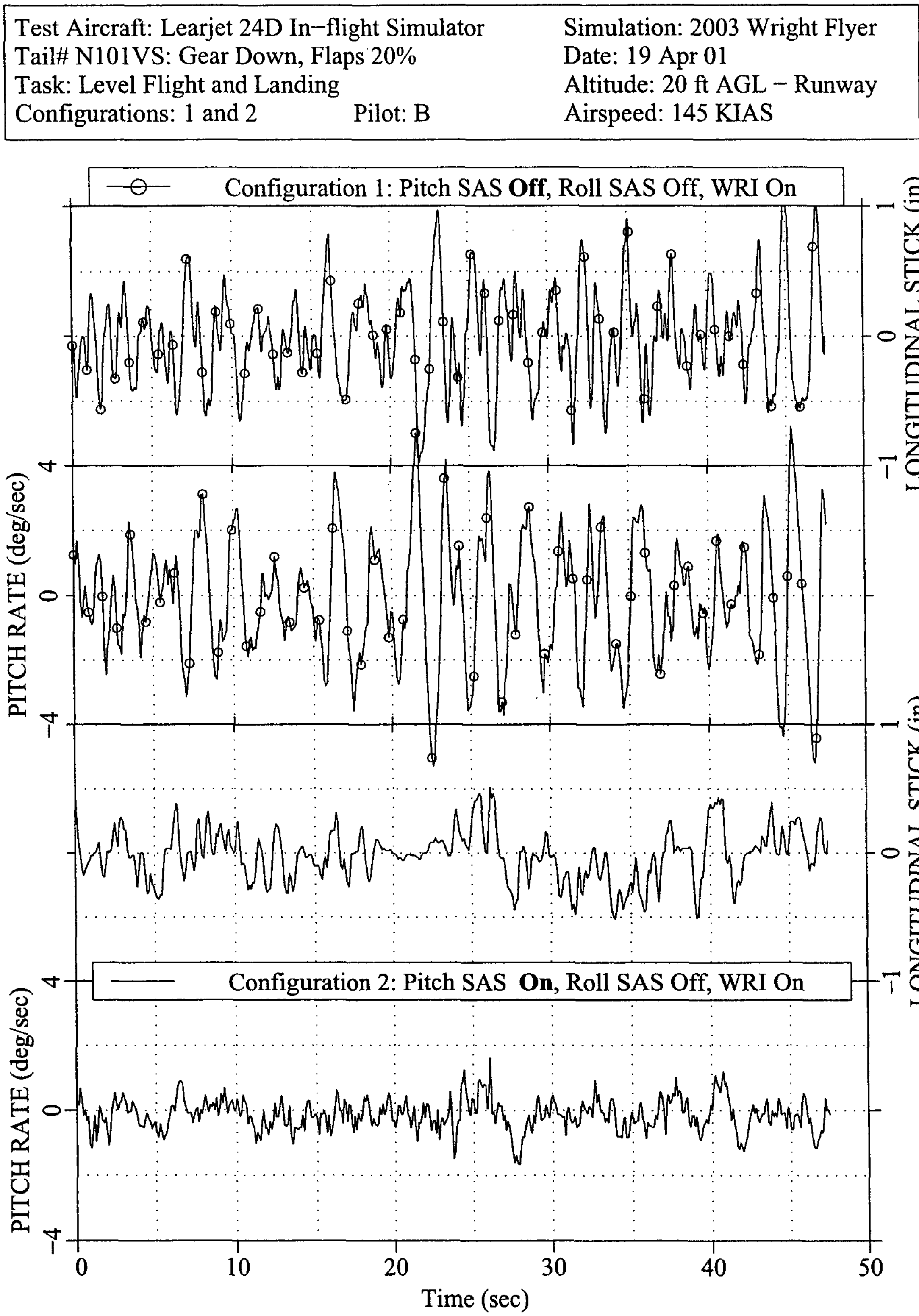

Figure G13 Pilot B Time History of Landing with Pitch SAS Off and On

Test Aircraft: Learjet 24D In–flight Simulator
Tail# N101VS: Gear Down, Flaps 20%
Task: Level Flight and Landing
Configurations: 1 and 2 Pilot: C

Simulation: 2003 Wright Flyer
Date: 20 Apr 01
Altitude: 20 ft AGL – Runway
Airspeed: 145 KIAS

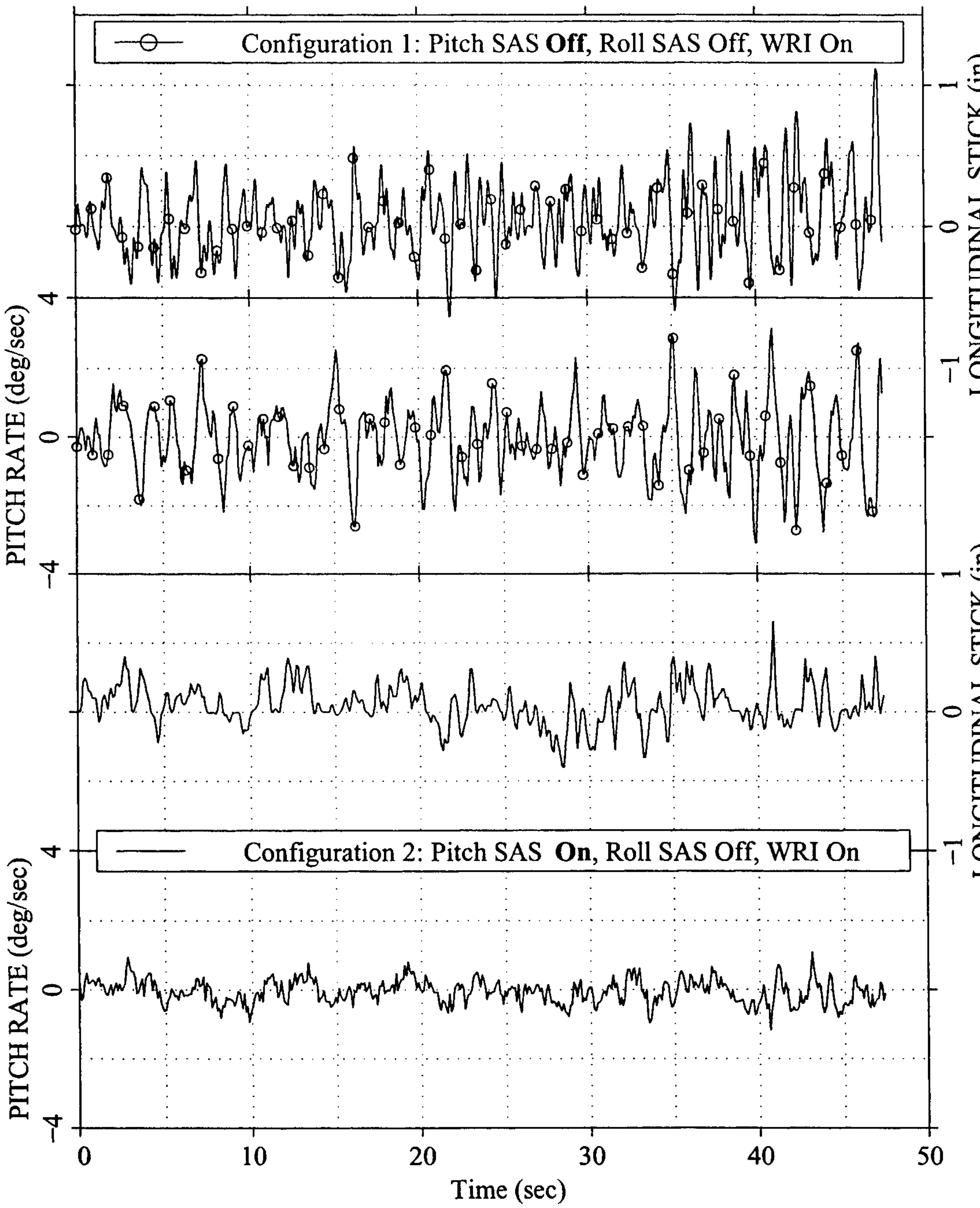

Figure G14 Pilot C Time History of Landing with Pitch SAS On and Off

Test Aircraft: Learjet 24D In–flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 20 Apr 01
Task: Level Flight and Landing	Altitude: 20 ft AGL – Runway
Configurations: 2 and 3 Pilot: A	Airspeed: 145 KIAS

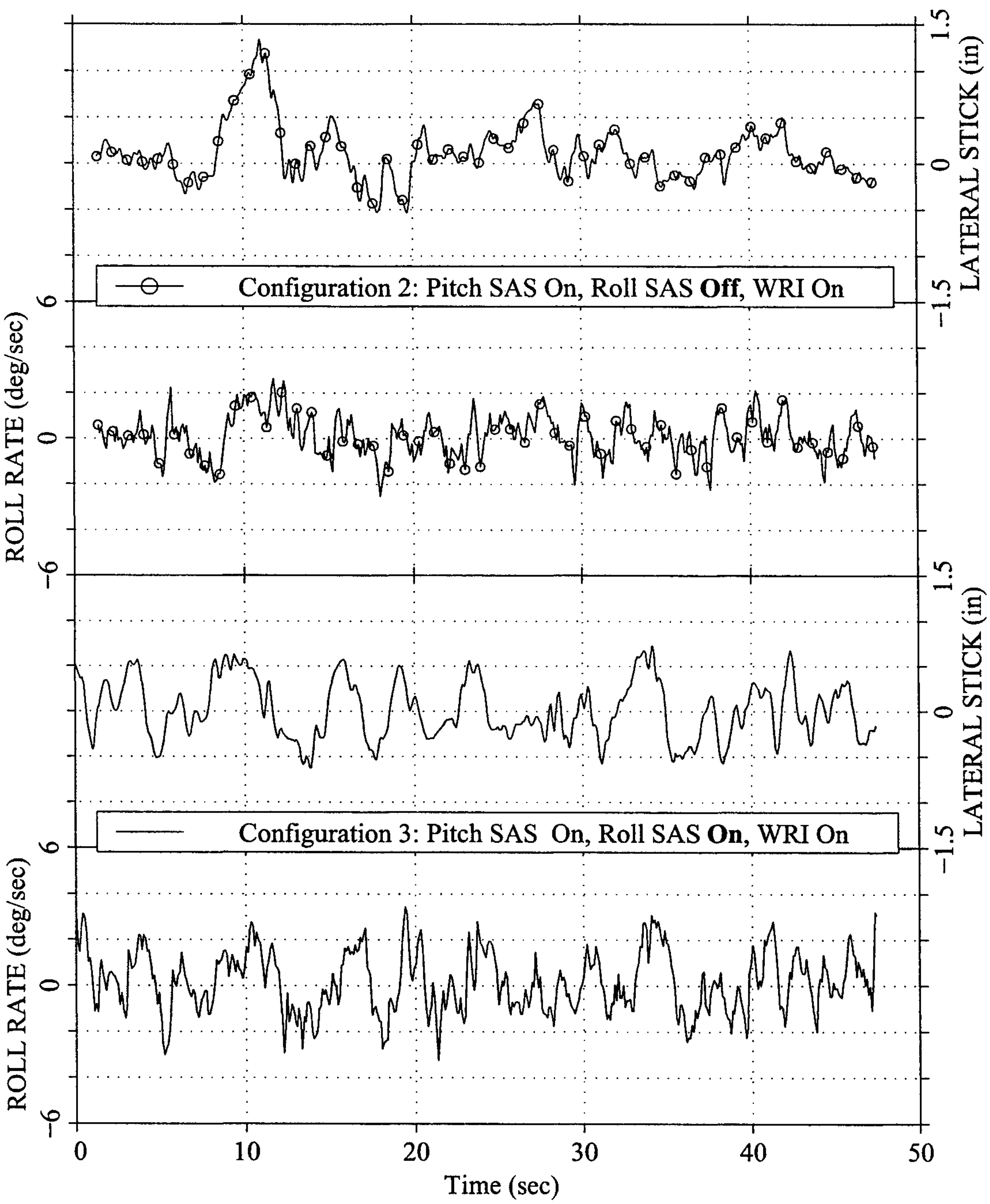

Figure G15 Pilot A Time History of Landing with Roll SAS Off and On

Test Aircraft: Learjet 24D In–flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 19 Apr 01
Task: Level Flight and Landing	Altitude: 20 ft AGL – Runway
Configurations: 2 and 3 Pilot: B	Airspeed: 145 KIAS

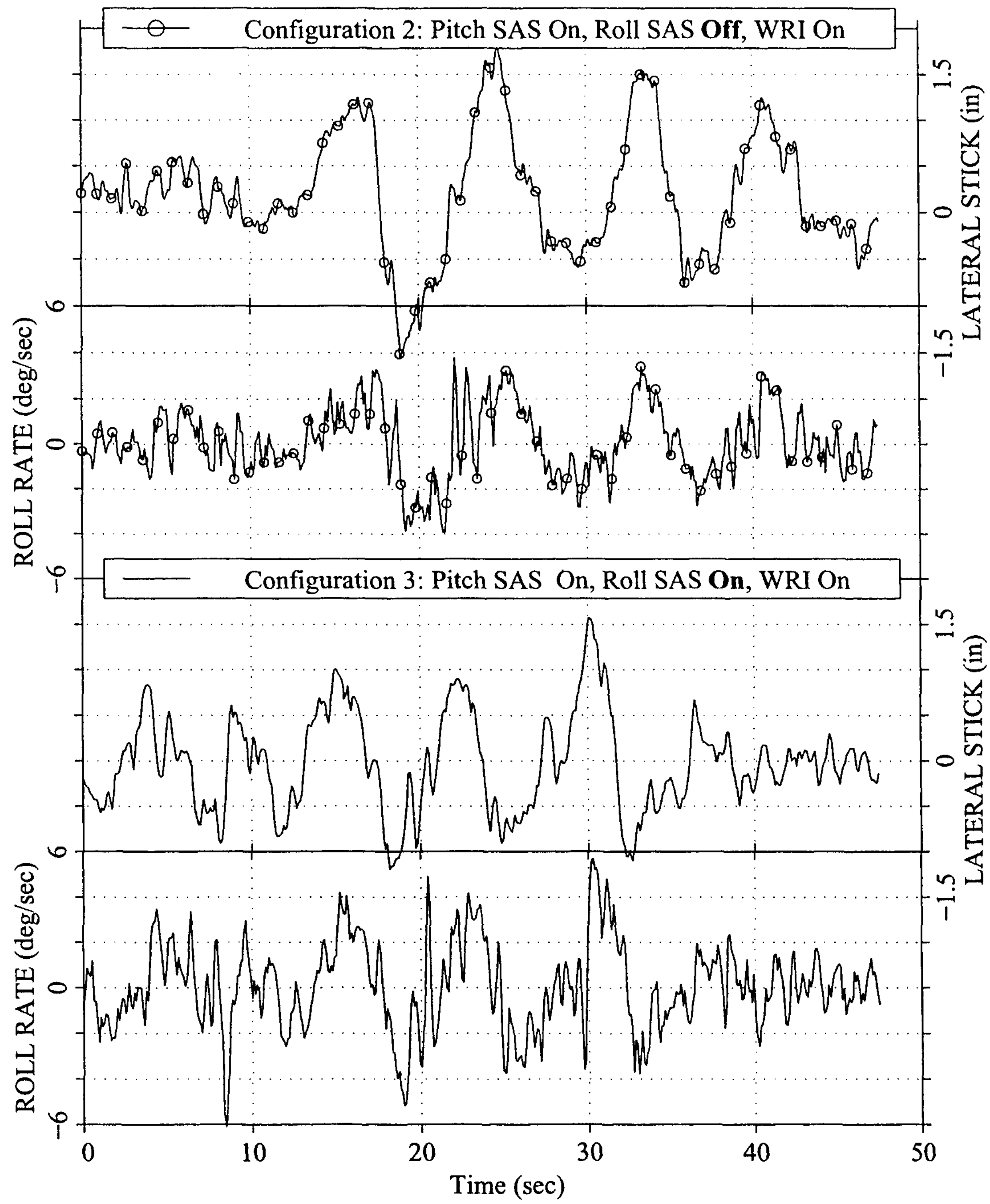

Figure G16 Pilot B Time History of Landing with Roll SAS Off and On

Test Aircraft: Learjet 24D In–flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 20 Apr 01
Task: Level Flight and Landing	Altitude: 20 ft AGL – Runway
Configurations: 2 and 3 Pilot: C	Airspeed: 145 KIAS

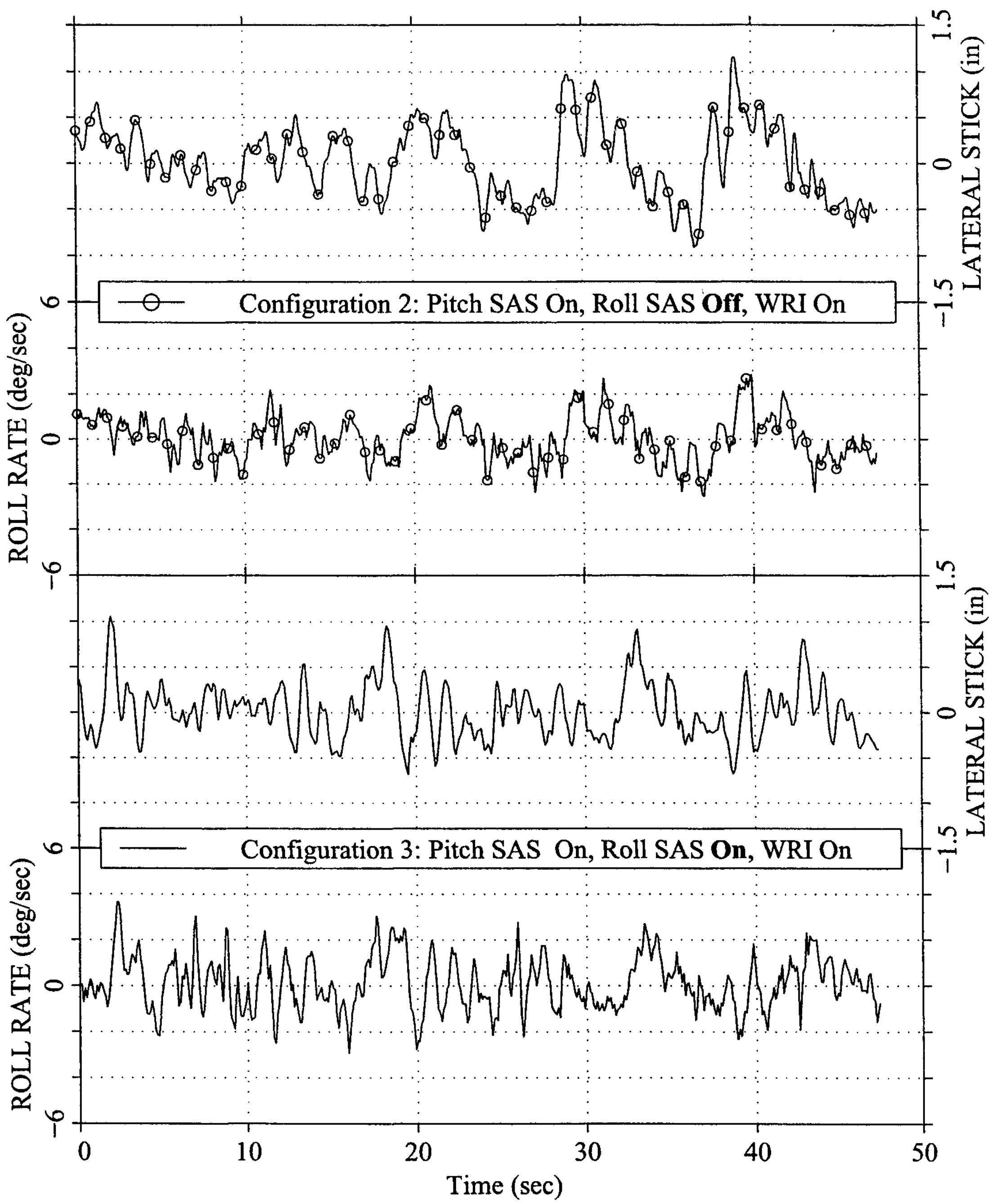

Figure G17 Pilot C Time History of Landing with Roll SAS Off and On

Test Aircraft: Learjet 24D In–flight Simulator
Tail# N101VS: Gear Down, Flaps 20%
Task: Level Flight and Landing
Configurations: 1 and 4 Pilot: A

Simulation: 2003 Wright Flyer
Date: 20 Apr 01
Altitude: 20 ft AGL – Runway
Airspeed: 145 KIAS

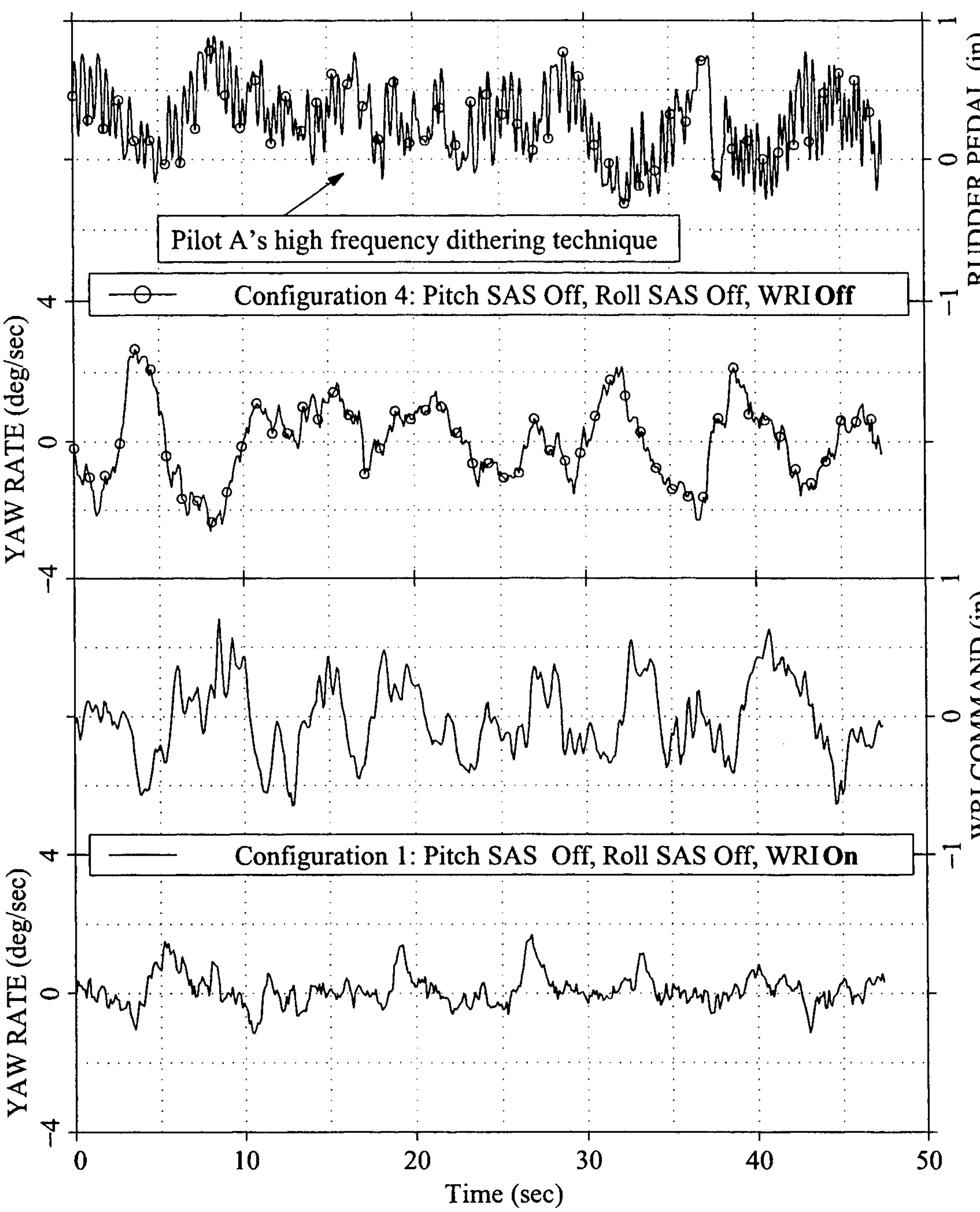

Figure G18 Pilot A Time History of Landing with WRI Off and On

Test Aircraft: Learjet 24D In–flight Simulator	Simulation: 2003 Wright Flyer
Tail# N101VS: Gear Down, Flaps 20%	Date: 19 Apr 01
Task: Level Flight and Landing	Altitude: 20 ft AGL – Runway
Configurations: 1 and 4 Pilot: B	Airspeed: 145 KIAS

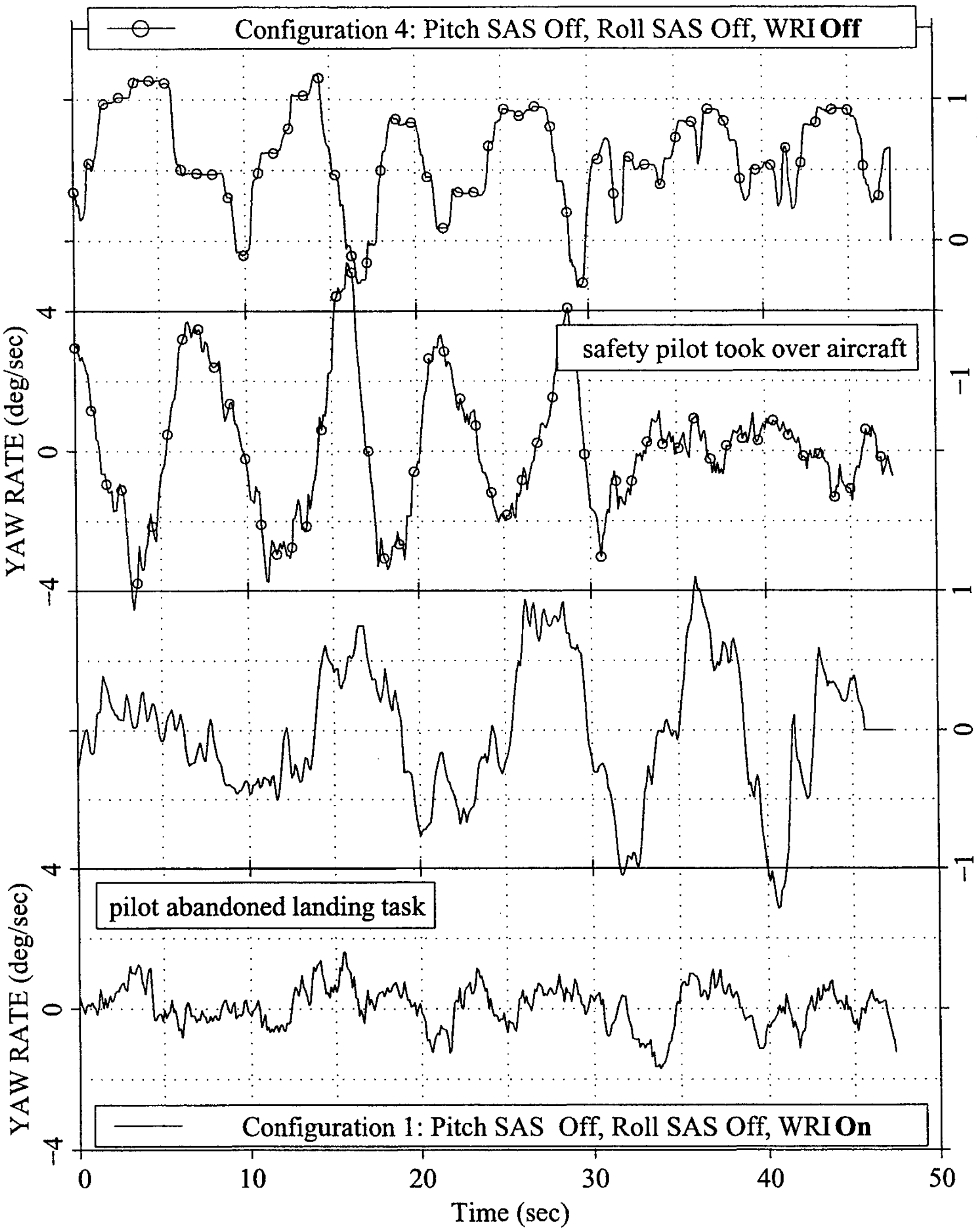

Figure G19 Pilot B Time History of Landing with WRI Off and On

Test Aircraft: Learjet 24D In–flight Simulator Tail# N101VS: Gear Down, Flaps 20% Task: Level Flight and Landing Configurations: 1 and 4 Pilot: C	Simulation: 2003 Wright Flyer Date: 20 Apr 01 Altitude: 20 ft AGL – Runway Airspeed: 145 KIAS

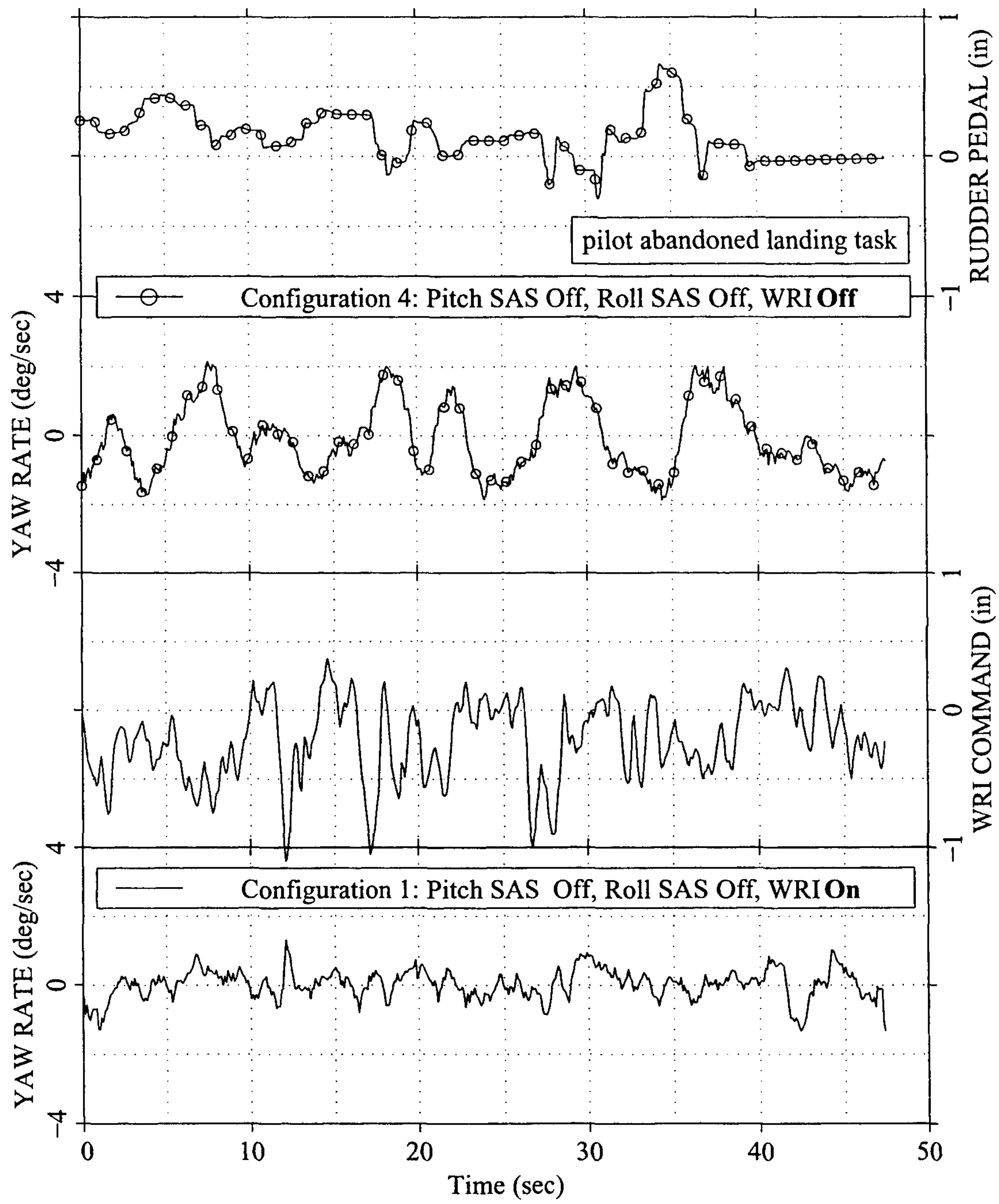

Figure G20 Pilot C Time History of Landing with WRI Off and On

APPENDIX H – DAILY/INITIAL FLIGHT TEST REPORTS

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DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. TAIL #
Lear 24	N101VS

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION # HAVE WRIGHT / D7985B	B. FLIGHT # / TEST POINTS 1 / See Below	C. DATE 18 Apr 01
D. FRONT COCKPIT *(Right + Left Seat)* Johansen & Deppe	E. FUEL LOAD 5100 lbs	F. JON M96J0200
G. REAR COCKPIT *(Rest of crew)* Jorris & Markofski	H. START UP GR WT / CG 13,000 / UNK	I. WEATHER Sct 120, winds 24020G26
J. TO TIME / SORTIE DURATION 1355L / 1.5	K. CONFIGURATION / LOADING Gear/20 Flaps/VSS engaged	L. SURFACE CONDITIONS 77 F, PA 2275 ft, Dry Rwy
M. CHASE ACFT / SERIAL NO C-12/215	N. CHASE CREW Haug & Evans	O. CHASE TO TIME / SORTIE TIME 1355 / 1.6

4. PURPOSE OF FLIGHT / TEST POINTS

The purpose of the flight was to evaluate up and away in flight four different configurations for the Wright Flyer aerodynamic model, using the Veridian Variable Stability Learjet In-flight Simulator (VSSLIS). These configurations were:

Config #	Pitch Stability augmentation System (SAS)	Roll SAS	Warp Rudder Interconnect (WRI)
1	OFF	OFF	ON
2	ON	OFF	ON
3	ON	ON	ON
4	OFF	OFF	OFF

The test points were:

1. Trim Shot / Dynamics — 10K ft / 145 KIAS, Gear down / Flaps 20°
2. Pitch/Bank/Heading Captures — 10K ft / 145 KIAS, Gear down / Flaps 20°
3. Phase 2: Pitch Pointing/Bank Matching — 10K ft / 145 KIAS, Gear down / Flaps 20°
4. Simulated Flare/Pitch Attitude Tracking — 10K ft / 145 KIAS, Gear down / Flaps 20°

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Aircraft Description:
The test item was an in-flight simulation of the aerodynamic math model of the 2003 Wright Flyer. Since the 2003 Wright Flyer has not been constructed yet, the 2003 Wright Flyer math model consists of stability derivatives from wind tunnel tests of the 1903 full-scale replica and stability derivatives from AIAA empirical methods. The 2003 Wright Flyer math model was simulated in the VVSLIS aircraft (tail# N101VS) using MATLAB/SIMULINK software. The stability derivatives and associated state space matrices for the 2003 Wright Flyer math model are shown in Appendix B of the Have Wright test plan.

Overall: All four configurations were flown at 10,000' MSL and 145 KIAS through low and high bandwidth flying qualities maneuvers with the C-12 used as a target for tracking tasks. The operational tasks were not accomplished due to time constraints. The preference of configurations was 3, 2, 1, and 4.

6. RECOMMENDATIONS

I felt that the adverse yaw was more objectionable than the negative spiral stability in roll. Investigate the handling qualities with a yaw damper. I think it would provide the greatest improvement besides the pitch damper, since the spiral is so slow and easily controllable.

COMPLETED BY	SIGNATURE	DATE
KENT-HARALD JOHANSEN, Capt, RNoAF	Kent Johansen	23 Apr 01

AFMC Form 5314 NOV 1947

PHASE 1:

Configuration 1 (WRI ON, Pitch SAS OFF, Roll SAS OFF):
First comment; You cannot take your hands off the controls. IE no trim shot. This configuration was highly unstable and rapidly diverged in pitch. Gentle Phase one maneuvers were performed in pitch, yaw and roll. These maneuvers consisted of Pitch doublets, Yaw doublets (excited with ailerons), Pitch Angle captures, Bank angle captures and Heading captures.

Pitch: There was no apparent delay from control input to aircraft response and it was very sensitive. The onset of the aircraft response was smooth, but escaladed quickly, so an opposite control pulse was required to slow it down. Constant "dithering" of the stick was required to maintain control. So for the pitch capture task, it only required a small control input in desired direction to get the pitch acceleration going, and then opposite control impulses to slow it down and stop it. As long as the inputs were small and the pitch rate was controlled there was no tendency to overshoot a desired pitch attitude. For pitch attitude changes of more than ±8° from level flight, large stick deflections were required to arrest the pitch rate, and with too high a bandwidth it would disengage the VSS due to AoA limits. At 8° nose high, the Learjet also became very close to stall, which activated the stick shaker. The workload flying this configuration was high, but as long as this was the only task the pilot had to concentrate on, it is doable without practice.

Yaw: After a step aileron input commanding roll, the first aircraft response was about 5° adverse yaw. Then after a 2-3 second delay the aircraft starts a slow roll. This excited the Dutch Roll, which was snaky and very lightly damped, with more than 8 overshoots.

Roll: Configuration one had negative spiral stability. Since the roll rate was so slow, there was no difficulty in stopping at the desired bank angle of up to 30°. To hold this bank a stick force out of turn of about 10 lbs was required.

Heading captures: With the adverse yaw being as big as it was, initially I would overshoot the desired heading. Once you start rolling out of bank, the adverse yaw pulls the nose across. After doing this a couple of times, you can compensate by leading the rollout about 5° more.

Configuration 2 (WRI ON, Pitch SAS ON, Roll SAS OFF):
The pitch SAS definitely lessened the workload flying the Wright flyer. It was highly damped in pitch, with none or maybe one overshoot following a pitch doublet ($\zeta = 0.6$). Doing a pitch capture was extremely easy; pull/push to desired pitch and just let go. There still was a lot of adverse yaw following a roll command, with an extremely large delay in roll response. After desired bank is set, opposite aileron is required to keep the bank. Large (almost full) stick deflection was required to roll back to level from a bank. Doing heading captures there still was a tendency to overshoot due to the adverse yaw in the rollout of the bank (10°).

Configuration 3 (WRI ON, Pitch SAS ON, Roll SAS ON):
With both pitch and roll SAS, the Wright flyer was very easy to fly. Highly damped in pitch, and with neutral spiral stability in roll, the only improvement that comes to my mind to make to this flyer next is a yaw damper. Following a roll input there still was a large adverse yaw, followed by the roll response, and the Dutch roll was snaky. The adverse yaw also still made me overshoot during heading captures, but pitch and bank captures were easy. The roll became more predictable, and less compensation was required to capture and hold a bank. Since I no longer had to hold opposite stick in to hold the bank, there was less stick deflection required to roll out of the bank, although the warp deflection probably still was the same with the SAS doing some of the work.

Configuration 4 (WRI OFF, Pitch SAS OFF, Roll SAS OFF):
WOW! I immediately entered a lateral-directional PIO. There was a slight learning curve to fly this configuration that I would not recommend to try for the first time close to the ground. The VSS disengaged for limits being exceeded after only 30 seconds trying to conquer the PIO. Second try I was able to control the aircraft, but the workload was very high, fighting the instability in pitch, and working hard with the rudder and stick in the lateral axis trying to fly straight. Some phase one maneuvers were performed:

Pitch: There was no apparent delay from control input to aircraft response and it was very sensitive. The onset of the aircraft response was smooth, but escaladed quickly, so an opposite control pulse was required to slow it down. Constant "dithering" of the stick was required to maintain control. So for the pitch capture task, it only required a small control input in desired direction to get the pitch acceleration going, and then opposite control impulses to slow it down and stop it. As long as the inputs were small and the pitch rate was controlled there was no tendency to overshoot a desired pitch attitude. For pitch attitude changes of more than ±8° from level flight, large stick deflections were required to arrest the pitch rate, and with too high a bandwidth it would disengage the VSS due to AoA limits. At 8° nose high, the Learjet also became very close to stall, which activated the stick shaker.

Yaw: After a step aileron input commanding roll, the first aircraft response was about 5° adverse yaw. Then after a 2-3 second delay the aircraft starts a slow roll. This excited the Dutch Roll, which I was unable to stop with rudder.

Roll: Since the roll rate was so slow, there was no difficulty in stopping at the desired bank angle of up to 30°. To hold this bank a stick force out of turn of about 10 lbs was required. The roll rate appeared to be more influenced by the Dutch roll, compared to config. 1.

Heading captures: With the adverse yaw being as big as it was, exciting the Dutch roll, the overshoot of the desired heading was dependent on where you were in the Dutch roll upon rollout.

Steady heading sideslip: A slowly varying steady heading sideslip was performed. The stick position required was not in the normal sense. $C_{l\beta}$ in the wrong direction. With 15° of left bank, ¾ right rudder and 10 lbs of right stick force the aircraft was tracking straight before the VSS disengaged due to top tail rolling moment or beta limit reached.

PHASE 2:

Configuration 1 (WRI ON, Pitch SAS OFF, Roll SAS OFF):

Pitch: From 1000 feet trail of C-12 target phase 2 HQDT was performed with the C-12 in straight and level flight, and with ±5° pulls/pushovers at a slow rate. There was no delay in pitch response, and with high bandwidth large deflection inputs the VSS disengaged due to AoA limits. **PIOR 3.**

Bank: From 1000 feet trail of C-12 target phase 2 HQDT bank matching was performed with the C-12 doing lazy 10 to 10° bank-to-bank rolls. Even though the C-12 rolled extremely slowly, with a period of about 10 seconds, the Wright flyer could not keep up. The roll response was so sluggish that it prevented me from getting into a high bandwidth. **PIOR 1.**

Simulated Flare: From a 3-4 wingspan route position with nose-tail separation, a simulated flare was performed with the C-12 as a ground horizon reference. Starting the descent, I continuously had to fight the aircraft that wanted to walk away from my desired pitch attitude. I was able to flare level with the C-12, without any overshoot. My technique was to use small pulse inputs to stop any undesired pitch changes that the aircraft did. **PIOR 3.**

Pitch Attitude Tracking: From a 3-4 wingspan route position with nose-tail clearance 45° aft of the C-12, which was in a 5° decent, HQDT pitch attitude tracking was performed. This being a translation maneuver, the Wright flyer would diverge in pitch before we would become level with the target where I would reverse the stick input. The result was that the VSS disengaged due to AoA limits. **PIOR 5.**

Configuration 2 (WRI ON, Pitch SAS ON, Roll SAS OFF):

Pitch: From 1000 feet trail of C-12 target phase 2 HQDT was performed with the C-12 in straight and level flight, and with ±5° pulls/pushovers at a slow rate. There was no apparent delay in pitch response, but it was more sluggish than without the SAS and the rate of pitch change followed the amplitude of the stick deflection to the point where the VSS disengaged due to AoA limits. **PIOR 1.**

Bank: From 1000 feet trail of C-12 target phase 2 HQDT bank matching was performed with the C-12 doing lazy 10 to 10° bank-to-bank rolls. Even though the C-12 rolled extremely slowly, with a period of about 10 seconds, the Wright flyer could not keep up. The roll response was so sluggish that it prevented me from getting into a high bandwidth. **PIOR 1.**

Simulated Flare: From a 3-4 wingspan route position with nose-tail separation, a simulated flare was performed with the C-12 as a ground horizon reference. This task was very easy, set desired pitch for glide path, milk it down, and wait till almost level before initiating a gentle flare with no tendency to overshoot. **PIOR 1.**

Pitch Attitude Tracking: From a 3-4 wingspan route position with nose-tail clearance 45° aft of the C-12, which was in a 5° decent, HQDT pitch attitude tracking was performed. With the pitch response being very sluggish, I ended up with a large oscillation around the target. This being a translation maneuver, the Wright flyer was able to build up in G during the time it took for the aircraft to translate from a low position to level with the target. Fear of over-G made me discontinue the HQDT without the VSS disengaging. **PIOR 3.**

Configuration 3 (WRI ON, Pitch SAS ON, Roll SAS ON):

Pitch: From 1000 feet trail of C-12 target phase 2 HQDT was performed with the C-12 in straight and level flight, and with ±5° pulls/pushovers at a slow rate. There was no apparent delay in pitch response, but it was more sluggish than without the SAS and the rate of pitch change followed the amplitude of the stick deflection to the point where the VSS disengaged due to AoA limits. **PIOR 1.**

Bank: From 1000 feet trail of C-12 target phase 2 HQDT bank matching was performed with the C-12 doing lazy 10 to 10° bank-to-bank rolls. Even though the C-12 rolled extremely slowly, with a period of about 10 seconds, the Wright flyer could not keep up. The roll response was sluggish, although it felt a little bit faster than without the Roll SAS. But this slow roll response prevented me from getting into a high bandwidth. **PIOR 1.**

Configuration 4 (WRI OFF, Pitch SAS OFF, Roll SAS OFF):

Pitch: From 1000 feet trail of C-12 target phase 2 HQDT was performed with the C-12 in straight and level flight, and with ±5° pulls/pushovers at a slow rate. There was no delay in pitch response, and with high bandwidth large deflection inputs the VSS disengaged due to AoA limits. I was unable to prevent oscillations in yaw, although only pitch inputs were made, and a bounded PIO was entered. **PIOR 4.**

Bank: From 1000 feet trail of C-12 target phase 2 HQDT bank matching was performed with the C-12 doing lazy 10 to 10° bank-to-bank rolls. The C-12 rolled extremely slow, with a period of about 10 seconds, the Wright flyer was able to keep up with this roll rate with the use of rudder into the roll. But the roll response was still so sluggish that it prevented me from getting into a high bandwidth. **PIOR 3.**

Simulated Flare: From a 3-4 wingspan route position with nose-tail separation, a simulated flare was performed with the C-12 as a ground horizon reference. Starting the descent, I continuously had to fight the aircraft that wanted to walk away from my desired pitch attitude, and the nose was oscillating uncommanded back and forth. I was able to flare level with the C-12, without any overshoot. But the oscillations in yaw were very uncomfortable, and highly objectionable for the landing phase. **PIOR 3.**

Pitch Attitude Tracking: From a 3-4 wingspan route position with nose-tail clearance 45° aft of the C-12, which was in a 5° decent, HQDT pitch attitude tracking was performed. This being a translation maneuver, the Wright flyer would diverge in pitch before we would become level with the target where I would reverse the stick input. The result was that the VSS disengaged due to AoA limits. **PIOR 5.**

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. TAIL #
Lear 24	N101VS

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION #	B. FLIGHT # / TEST POINTS	C. DATE
HAVE WRIGHT / D3725A	2 / See Below	18 Apr 01
D. FRONT COCKPIT *(Right and Left Seat)*	E. FUEL LOAD	F. JON
Haug & Deppe	5100 lbs	M96J0200
G. REAR COCKPIT *(Rest of Crew)*	H. START UP GR WT / CG	I. WEATHER
Colebank & Markofski	13,000 / UNK	Clear, winds 22020G25
J. TO TIME / SORTIE DURATION	K. CONFIGURATION / LOADING	L. SURFACE CONDITIONS
1655L / 1.6	Gear/20 Flaps/VSS engaged	73 F, PA 2312 ft, Dry Rwy
M. CHASE ACFT / SERIAL NO	N. CHASE CREW	O. CHASE TO TIME / SORTIE TIME
C-12/215	Johansen & Cooley	1653L / 1.7

4. PURPOSE OF FLIGHT / TEST POINTS

The purpose of the flight was to evaluate in flight four different configurations for the Wright Flyer aerodynamic model, using the Veridian Variable Stability Learjet Inflight Simulator (VSSLIS). These configurations were:

Configuration 1: Pitch Stability Augmentation System (SAS) - OFF; Roll SAS – OFF; Warp Rudder Interconnection (WRI) – ON

Configuration 2: Pitch SAS - ON; Roll SAS – OFF; WRI – ON

Configuration 3: Pitch SAS - ON; Roll SAS – ON; WRI – ON

Configuration 4: Pitch SAS - OFF; Roll SAS – OFF; WRI – OFF

The test points were:

1. Trim Shot / Dynamics	10K ft / 145 KIAS, Gear down / Flaps 20°
2. Pitch/Bank/Heading Captures	10K ft / 145 KIAS, Gear down / Flaps 20°
3. Phase 2: Pitch Pointing/Bank Matching	10K ft / 145 KIAS, Gear down / Flaps 20°
4. Simulated Flare/Pitch Attitude Tracking	10K ft / 145 KIAS, Gear down / Flaps 20°
5. Tower FlyBy	100 ft AGL / 145 KIAS, Gear down / Flaps 20°

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Aircraft Description: The test item was an in-flight simulation of the aerodynamic math model of the 2003 Wright Flyer. Since the 2003 Wright Flyer has not been constructed yet, the 2003 Wright Flyer math model consists of stability derivatives from wind tunnel tests of the 1903 full-scale replica and stability derivatives from AIAA empirical methods. The 2003 Wright Flyer math model was simulated in the VVSLIS aircraft (tail# N101VS) using MATLAB/SIMULINK software. The stability derivatives and associated state space matrices for the 2003 Wright Flyer math model are shown in Appendix B of the Have Wright test plan.

Overall: All four configurations were flown at 10,000' MSL and 145 KIAS through low and high bandwidth flying qualities maneuvers with the C-12 used as a target for tracking tasks. Configuration 2 (WRI ON, Pitch SAS ON, and Roll SAS OFF) was flown on the tower flyby line, it had been judged as the best configuration at altitude. Further operational tasks were not accomplished due to time constraints. The preference of configurations was 2, 3, 1, and 4.

Configuration 1 (WRI ON, Pitch SAS OFF, Roll SAS OFF):

Test Points 1 & 2: As soon as the VVSLIS was engaged with this configuration, pitch instability was evident. By keeping inputs small with tight control, pitch errors were minimized, but it was obvious with bigger excursions that this configuration would be challenging for operational tasks and may be adversely affected by gusts. There was no notable delay in pitch response. The onset of pitch response was initially slightly abrupt and then quickly tended to "dig in" with an ever-increasing pitch rate leading to a tendency to rapidly overshoot desired pitch attitudes. Pitch response was initially difficult to predict, but with time, a shallow learning curve developed that allowed better predictability. Arresting pitch rate required considerable compensation and even with a shallow learning curve, it was difficult to precisely fly with

6. RECOMMENDATIONS

R1: Fly Configuration 2 first for operational tasks.

R2: Approach operational tasks in Configuration 4 with caution and constant vigilance for task fixation or saturation.

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zero pitch rate. Workload for pitch control was high. The configuration was reasonably comfortable in the lateral/directional axes. Roll response was slow but adequate, adverse yaw was evident but not objectionable. Opposite stick was required to maintain bank angle and bank captures out to 30 degrees were attained. Workload for roll control was medium.

Test Points 3 & 4: During pitch and roll tracking and during simulated flare and pitch attitude tracking with the C-12 as target, similar observations were made with a few additions. During HQDT while pitch pointing, undesirable motion was obvious. PIOR: R. During simulated flare tasks, a potential tendency to balloon was noted when increasing pitch to arrest sink rate because of the tendency to overshoot the change in pitch attitude during the flare. Pitch control requires considerable compensation and handling qualities are objectionable due to the divergent tendencies in the pitch axis.

Configuration 2 (WRI ON, Pitch SAS ON, Roll SAS OFF):

Test Points 1 & 2: This was the most comfortable configuration to fly. There was no delay in pitch response. Pitch response was smooth, linear, and predictable. Residual pitch motion was virtually nonexistent or deadbeat. Capturing pitch attitudes was fairly easy with no observed tendency to under or overshoot. Pitch attitudes could not be changed as rapidly. This could be a factor if dramatic nose low pitch attitudes and high sink rates are encountered near the ground during operational tasks, but highly unlikely. Workload for pitch control was low. The configuration was reasonably comfortable in the lateral/directional axes. Roll response was slow but adequate, adverse yaw was evident but not objectionable. Opposite stick was required to maintain bank angle and bank captures out to 30 degrees were attained. Workload for roll control was medium.

Test Points 3 & 4: No significantly different observations were made while tracking the target. No PIO tendencies were observed and in general, the configuration is comfortable to fly with no objectionable handling qualities and just one thing to watch out for: the inability to change pitch attitude rapidly. **R1: Fly Configuration 2 first for operational tasks.**

Configuration 3 (WRI ON, Pitch SAS ON, Roll SAS ON):

Test Points 1 & 2: This was the most augmented configuration. Pitch response was predictably very similar to that seen with Configuration 2. In the lateral/directional axes, the Roll SAS appeared to reduce roll response making it slower and heavier, requiring larger and longer inputs to get expected responses after flying the previous configurations with the roll SAS off. In addition, the adverse yaw was significantly greater than observed with the Roll SAS off. Workload for roll control was low, but the adverse yaw was objectionable.

Test Points 3 & 4: No significantly different observations were made while tracking the target. No PIO tendencies were observed. The reduced roll responsiveness could become a factor during operational tasks near the ground, especially if gusts are encountered, because of the slow roll rates with small inputs and the displacement required for faster roll rates.

Configuration 4 (WRI OFF, Pitch SAS OFF, Roll SAS OFF):

Test Points 1 & 2: This configuration was a handful from the word GO! In addition, to the known instability in pitch and requisite close control to null out pitch rate divergence, directional control required continuous attention. Yaw control appeared to be entirely dependent on the pilot. The nose of the aircraft could be pointed directionally using the rudder pedals without any significant impact on the roll or pitch axes. Singlet rudder inputs would eventually come back toward neutral, but excited an objectionable snaky Dutch roll with very little, if any, damping. The fact that the nose could be pointed somewhat independently was intriguing; the fact that it had to be done to avoid slipping sideways through the air indefinitely was objectionable. Bank angle captures up to 20 degrees were attained with a technique of leading (by about ½ second) with pro turn rudder and leading the nulling of the roll rate with opposite rudder. Nearly continuous small step rudder inputs were effective to avoid sideslip on the aircraft. The need for these inputs was not always readily apparent at altitude. Steady heading sideslips were attempted and achieved through about ½ rudder deflection before aircraft limits were approached. It was clear that the rudder was very effective and powerful during these maneuvers. Workload for pitch control was high, workload for roll control was medium, and workload for yaw control was high. The combination of these largely independent workloads makes this configuration very unpredictable. It may appear that things are going very well with only small excursions in any axis and small control inputs required. But in an instant, it can turn ugly with large excursions and responding large inputs in the pitch and yaw axes, pilot task saturation, and loss of control. **R2: Approach operational tasks in Configuration 4 with caution and constant vigilance for task fixation or saturation.**

Test Points 3 & 4: During pitch and roll tracking, simulated flares and pitch attitude tracking the workload to control the aircraft was high. Undesirable motions were very evident, especially in yaw, and a bounded PIO tendency was experienced in yaw. **Repeat R2.**

100' AGL Tower FlyBy Configuration 2 (WRI ON, Pitch SAS ON, Roll SAS OFF): This was my first attempt at an operational task in the VVSLIS simulating the Wright Flyer. Desired performance was to hold level flight at 100' AGL over the tower flyby line for at least 30 seconds, adequate performance was to hold level flight for at least 15 seconds. I setup for the task by descending from about 2000' AGL while roughly aligned with the flyby line. Maintaining pitch attitude and correcting for small lateral offsets during the descent was relatively easy. As we descended down below 300' AGL, outside visual reference began to provide distinctive quantitative and qualitative information. One clear example was the nóticeable effect of a right to left crosswind pushing the aircraft laterally off the flyby line. The direction of the crosswind and the relative magnitude were clearly visible. Also clearly visible was the effect of a crabbing technique to minimize lateral offset. While level at 100' AGL I found it to be relatively simple to precisely control pitch. However, I was making significant lateral inputs to keep the aircraft directly above the flyby line although not required for the task. I achieved desired performance with moderate compensation. **CHR: 4, PIOR: 1**. At the completion of the task, I increased the pitch attitude about 3 degrees and started a shallow climb to approximate a possible rotation and takeoff attitude. The pitch was precisely controllable and the rotation felt natural and was not objectionable.

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
Lear-24	N101VS

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO HAVE WRIGHT	B. FLIGHT NO / DATA POINT 3/See below	C. DATE 19 Apr 01
D. FRONT COCKPIT *(Right Seat)* Jansen/Deppe	E. FUEL LOAD 5100	F. JON M96J0200
G. REAR COCKPIT *(Jump Seat)* Casado/Markofski	H. START UP GR WT / CG 13000/Unk	I. WEATHER Clear
J. TO TIME / SORTIE TIME 0830 (L) / 1.5	K. CONFIGURATION / LOADING 20% Flaps/Gear Down	L. SURFACE CONDITIONS 270/06, dry
M. CHASE ACFT / TAIL NO C-12 / 1215	N. CHASE CREW Edwards / Haug	O. CHASE TO TIME / SORTIE TIME 0828 / 1.6

4. PURPOSE OF FLIGHT / TEST POINTS

The purpose of the flight was to evaluate in flight four different configurations for the Wright Flyer aerodynamic model, using the Veridian Variable Stability Learjet Inflight Simulator (VSSLIS). These configurations were:

Configuration 1: Pitch Stability Augmentation System (SAS) - OFF; Roll SAS – OFF; Wing Rudder Interconnection (WRI) – ON

Configuration 2: Pitch SAS - ON; Roll SAS – OFF; WRI – ON

Configuration 3: Pitch SAS - ON; Roll SAS – ON; WRI – ON

Configuration 4: Pitch SAS - OFF; Roll SAS – OFF; WRI – OFF

The test points were:

1. Trim Shot / Dynamics	10K ft / 145 KIAS,	Gear down / Flaps 20°
2. Pitch/Bank/Heading Captures	10K ft / 145 KIAS,	Gear down / Flaps 20°
3. Phase 2: Pitch Pointing/Bank Matching	10K ft / 145 KIAS,	Gear down / Flaps 20°
4. Simulated Flare/Pitch Attitude Tracking	10K ft / 145 KIAS,	Gear down / Flaps 20°
5. Tower FlyBy	100 ft AGL / 145 KIAS,	Gear down / Flaps 20°

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Aircraft Description: The test aircraft was the VSSLIS.

Overall Results: Pilot Rankings: in priority order.

1. Configuration 2
2. Configuration 3
3. Configuration 1
4. Configuration 4

Trim Shot / Dynamics: A trim shot at 10K ft and 145 KIAS, followed by dynamics investigation, was performed for every configuration. In those configurations with the Pitch SAS OFF, the pilot had to perform active control of the aircraft in the longitudinal axis to keep it in tolerances, showing static longitudinal instability. The lateral axis was statically stable for all the configurations except configuration 4, showing a very well damped Dutch Roll (DR) with the Roll SAS ON and a snaky DR with the Roll SAS OFF.

Pitch/Bank/Heading Captures: Open loop maneuvers (captures) were performed at 10K ft and 145 KIAS for every configuration. Pitch, Bank and Heading captures were performed for the three first configurations, without using the rudder pedals. For configuration 4, in which the use of the rudder pedals was allowed, a Slowly Varying Side Slip was also performed. All the configurations showed a very steep learning curve, allowing the pilot to feel comfortable after a few captures. However, the differences among them were evident. Configuration 1 (Pitch SAS - OFF; Roll SAS – OFF; WRI – ON) was easily controllable in pitch using high bandwidth inputs to hold the required attitude. In roll, this configuration showed spiral instability (the pilot claimed it was necessary to apply opposite stick deflection to hold the required bank angle) with very slow roll rate and slight adverse yaw. The configuration 2 (Pitch SAS - ON; Roll SAS – OFF; WRI – ON) was easy and predictable in pitch with tendency to undershoot, although the capture did not require high bandwidth inputs. In roll, no difference was noticed with respect to configuration 1. Configuration 3 (Pitch SAS - ON; Roll SAS – ON; WRI – ON) added an augmentation system

6. RECOMMENDATIONS

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in the lateral axis. In this case, the workload to hold the required attitude was less, but the adverse yaw was objectionable. Finally, configuration 4 was evaluated. With this configuration, the pilot claimed it was necessary to apply high bandwidth inputs both in the stick and in the rudder pedals to hold the required attitude. Also, adverse yaw and an easy tendency to excite the DR were noticed. Two SHSS, one left rudder and one right rudder, were performed showing negative dihedral effect (stick in the same direction than the rudder), which joined to the adverse yaw, made the aircraft difficult to hold in the required heading. However, the learning curve was very steep and the aircraft was controllable and even easy to fly.

Phase 2: Pitch Pointing/Bank Matching: Attitude matching and Phase 2 Handling Qualities During Tracking (HQDT) maneuvers in trail (1000 ft behind, 10K ft and 145 KIAS) were performed using a C-12 as target. Both investigations in pitch (+/- 5° pulls/pushovers and HQDT) and roll (+/- 10° bank and HQDT) were performed for every configuration. Configuration 1 (Pitch SAS - OFF; Roll SAS – OFF; WRI – ON) was sluggish in pitch requiring high bandwidth inputs to hold the attitude, but showing undesirable motion during the HQDT. Pitch Pilot In the loop Oscillation Rating (PIOR) 3. Roll, was also sluggish, requiring almost full deflection to perform HQDT with tendency to overshoot. Roll PIOR 2. Configuration 2 (Pitch SAS - ON; Roll SAS – OFF; WRI – ON) had the Pitch SAS activated, showing a very good onset and predictable behavior with slight tendency to overshoot. Pitch PIOR 2. Configuration 3 (Pitch SAS - ON; Roll SAS – ON; WRI – ON) added a SAS in both axes. In roll, it showed a slight PIO tendency with objectionable adverse yaw, making difficult to hold the attitude and performed the roll changes. Roll PIOR 4. Finally, configuration 4 showed a controllable roll rate and slight adverse yaw requiring active high bandwidth use of the rudder to hold the attitude. During the HQDT heavy and large deflections in both rudder and stick were applied. However, this configuration was comfortable to fly. Roll PIOR 2.

Simulated Flare/Pitch Attitude Tracking: Simulated flare and attitude tracking with the target 3-4 wingspans separation and 45°- 60° forward were performed to pre-evaluate the operational tasks. Configuration 1 (Pitch SAS - OFF; Roll SAS – OFF; WRI – ON) showed tendency to overrotate, making the pilot the maneuver. However, it was easy to stabilize. PIOR 3 in both maneuvers. Configuration 2 (Pitch SAS - ON; Roll SAS – OFF; WRI – ON) was lagging the target in both maneuvers, although did not show tendency to bubble and its behavior was also linear. PIOR 2 in both maneuvers. Configuration 3 (Pitch SAS - ON; Roll SAS – ON; WRI – ON) showed the best behavior during the flare without using lateral inputs. Only small corrections were applied. PIOR 1 during simulated flare. Finally, Configuration 4 was very demanding with intense workload. The snaky DR was easily excited. PIOR during the flare 3.

Tower FlyBy: Returning Base, a Tower FlyBy at 100 ft AGL and 145 KIAS using configuration 4 was performed. Desired criteria was to hold level flight for at least 30 seconds and adequate criteria was to hold level flight for at least 15 seconds. The pilot achieved desired criteria with winds 240 at 16. In this case, the pilot technique (as during the previous investigation) showed to be effective to fight against the pitch instability and the anhedral effect. PIOR 3 and Cooper Harper Rating (CHR) 6 were assigned during the accomplishment of this task.

Conclusions and Recommendations: Pitch SAS definitely decreases workload. The roll SAS increases the roll rate and alleviates out of turn direction stick forces when established in a turn, however, the adverse yaw was greater than the roll SAS off configurations when entering and exiting turns, this was very disconcerting and objectionable. The out of turn stick forces with the roll SAS disengaged are not objectionable and do not present a foreseeable problem when considering the operational environment of the 2003 Wright Flyer. The piloting techniques that worked the best were step inputs to set desired attitude followed by very small amplitude, high bandwidth inputs to maintain attitude. By keeping the all three attitudes within about 2-3 degrees with high bandwidth inputs, the aircraft was controllable for the tasks. Allowing the attitudes outside of 2-3 degrees dramatically increases the workload in that axis and causes the crosscheck of the performance in the other axes to break down. The result is a decrease in performance and large, potentially dangerous, oscillations in the pitch and yaw axes.

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE: Lear 24	2. TAIL #: N101VS	
3. CONDITIONS RELATIVE TO TEST		
A. PROJECT / MISSION # HAVE WRIGHT / D7555A	B. FLIGHT # / TEST POINTS 4 / See Below	C. DATE 19 Apr 01
D. FRONT COCKPIT *(Right + Left Seat)* Johansen & Deppe	E. FUEL LOAD 5100 lbs	F. JON M96J0200
G. REAR COCKPIT *(Rest of crew)* Colebank & Markofski	H. START UP GR WT / CG 13,000 / UNK	I. WEATHER Few 200, winds 24020G28
J. TO TIME / SORTIE DURATION 1159L / 1.6	K. CONFIGURATION / LOADING Gear/20 Flaps/VSS engaged	L. SURFACE CONDITIONS 18°C, PA 2284 ft, Dry Rwy
M. CHASE ACFT / SERIAL NO N/A	N. CHASE CREW	O. CHASE TO TIME / SORTIE TIME

4. PURPOSE OF FLIGHT / TEST POINTS

The purpose of the flight was to evaluate in flight four different configurations for the Wright Flyer aerodynamic model, using the Veridian Variable Stability Learjet In-flight Simulator (VSSLIS). These configurations were:

Config #	Pitch Stability augmentation System (SAS)	Roll SAS	Warp Rudder Interconnect (WRI)
1	OFF	OFF	ON
2	ON	OFF	ON
3	ON	ON	ON
4	OFF	OFF	OFF

The test points were:

1. Tower FlyBy — 100 ft AGL / 145 KIAS, Gear down / Flaps 20°
2. Sustained Level Flight over Runway — 20 ft AGL / 145 KIAS, Gear down / Flaps 20°
3. Landing — Runway surface / 145 KIAS, Gear down / Flaps 20°

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Aircraft Description:
The test item was an in-flight simulation of the aerodynamic math model of the 2003 Wright Flyer. Since the 2003 Wright Flyer has not been constructed yet, the 2003 Wright Flyer math model consists of stability derivatives from wind tunnel tests of the 1903 full-scale replica and stability derivatives from AIAA empirical methods. The 2003 Wright Flyer math model was simulated in the VVSLIS aircraft (tail# N101VS) using MATLAB/SIMULINK software. The stability derivatives and associated state space matrices for the 2003 Wright Flyer math model are shown in Appendix B of the Have Wright test plan.

Overall: Tower flybys were flown with all configurations prior to proceeding to the level flight / landing task. All four configurations were flown twice during the sustained level flight over the runway and landing tasks except for config 4, which was only flown once due to time constraints. Configurations 2 and 3 were quite comfortable to fly and land. Configurations 1 and 4 were very challenging to fly. Both resulted in safety pilot takeover during landing tasks just prior to touch down due to very uncomfortable pitch oscillations. The winds were very gusty, and I doubt the 2003 Wright Flyer will fly in these conditions. The necessary thrust changes required controlling airspeed and the gust drove the workload up, but on the other hand I was flying with fingertip control on the stick. There will be another ball game when bigger muscles in the arm start controlling wing warp etc.

6. RECOMMENDATIONS

Pitch SAS is a must for control. Without the pitch SAS a PIO is unavoidable, and with the high gain this results in during landing, safety will be a factor. With the pitch SAS the workload was decreased dramatically, and the most objectionable characteristic was the adverse yaw. If the winds are not gusty, taking off to fly straight and then land is not going to impose a problem. The roll SAS gave a little bit better roll response, and made it more comfortable to fly, but I see this as a nice to have feature, and not a necessity.

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Tower flyby:

Performance criteria for tower flybys were set to:
Desired criteria: Hold level flight for at least 30 seconds
Adequate criteria: Hold level flight for at least 15 seconds

Configuration 3 (WRI ON, Pitch SAS ON, Roll SAS ON):
Lined up with the tower flyby line the VSS was engaged at 3000 feet MSL. The safety pilot was controlling the throttles to maintain desired speed. The winds were very gusty (230 20G28), which made it a little more challenging. This configuration was easy to control; I set desired pitch for the descent to the flyby line, and leveled off 100 agl. Small control inputs with the finger tips holding the stick made it easy to correct pitch errors caused by wind gusts / throttle corrections and control the altitude. The workload was low, and I was able to keep a cross check with the altimeter and airspeed. Desired criteria for level flight was met, and a go around was initiated. It was easy to establish a slight climb and subsequently level off. **CHR 3 PIOR 1**

Configuration 1 (WRI ON, Pitch SAS OFF, Roll SAS OFF):
Lined up with the tower flyby line the VSS was engaged at 3000 feet MSL. The safety pilot was controlling the throttles to maintain desired speed. The winds were very gusty (220 23G30), which made it a little more challenging. Dithering of the stick was required to control pitch departure. I was able to keep a cross check of altimeter and airspeed, but the workload was high. Desired criteria were met. **CHR 6 PIOR 3**

Configuration 4 (WRI OFF, Pitch SAS OFF, Roll SAS OFF):
Lined up with the tower flyby line the VSS was engaged at 3000 feet MSL. The safety pilot was controlling the throttles to maintain desired speed. The winds were very gusty (230 23G30), which made it a little more challenging. Very high workload, it was difficult to bring the cross check inside the aircraft to check the altimeter. Tight control necessary in both pitch and yaw, which made me very tense. I was not able to keep the nose tracking straight with rudder control. Desired criteria for level flight were met. **CHR 7 PIOR 3**

Configuration 2 (WRI ON, Pitch SAS ON, Roll SAS OFF):
Lined up with the tower flyby line the VSS was engaged at 3000 feet MSL. The safety pilot was controlling the throttles to maintain desired speed. The winds were very gusty (220 23G30), which made it a little more challenging. Sluggishness in roll deteriorated my ability to keep the aircraft wings level, but it was still "comfortable" to fly. Maintaining level flight was easy, and desired criteria were met. **CHR 4 PIOR 2**

Level Flight / Landing task:
1. Attempt to hold level flight for 30 seconds
2. Call planned touchdown point and transition to landing task
3. Gently descend until touchdown occurs **without changing power setting**
4. Safety pilot assess landing as soft, firm, or hard and call aim point miss distance (long or short) and centerline miss distance (left or right)

Performance criteria for level flight / landing were set to:

LEVEL FLIGHT
Desired criteria: Hold level flight for at least 30 seconds over runway
Adequate criteria: Hold level flight for at least 15 seconds over runway

LANDING
Desired criteria: From sustained level flight over the runway (20 feet AGL goal), softly land within ± 500 feet of an aim point and ± 10 feet of centerline.
Adequate criteria: From sustained level flight over the runway (20 feet AGL goal), firmly (or softly) land within ± 1000 feet of an aim point and ± 20 feet of centerline, adequate

Configuration 3 (WRI ON, Pitch SAS ON, Roll SAS ON):
From south reentry at 3300 feet MSL the VSS was engaged lined up with the runway. It was a simple task to descend to 20 feet agl and maintain altitude. There were some pitch changes due to the very gusty winds (210 21G30), but small inputs on the stick arrested any climb / descent. The aircraft feels very stable and comfortable. The 30 second level flight criteria was easily met **CHR 3 PIOR 1** on both attempts, but we landed long **CHR 4 PIOR 1** on the first attempt due to being forced to try to put it down by 5000 feet remaining marker. On the second and subsequent attempts, we started the hack earlier, which gave me enough room to plan for the touch down point, and we were able to meet desired criteria for landing **CHR 3 PIOR 1.** The technique I used for the landing task in this configuration was to set a slow descent rate and just wait for it to touch down.

Configuration 2 (WRI ON, Pitch SAS ON, Roll SAS OFF):
From south reentry at 3300 feet MSL the VSS was engaged lined up with the runway. (Winds 210v240 24G30) The gusty wind shook the aircraft around a little, and the sluggish roll response made it challenging to keep the wings level. I had to put a big aileron input to roll the aircraft level after a gust, and with the coupled adverse yaw, this resulted in an uncomfortable oscillation down the runway **CHR 4 PIOR 3**. For the landing task, I used the same technique as for config 3, but with the snaky roll / yaw oscillation this landing was not as comfortable, and induced a high gain. Desired criteria was met in both tasks **CHR 4 PIOR 3**. On the second attempt (wind 210 21G29) I did not end up in the roll oscillation mode, and was able to keep the wings level, which reduced my workload. The winds did not feel as gusty, and the safety pilot was making less power correction. Only adequate performance was met for landing distance, although it was soft. Level flight: **CHR 3 PIOR 2**, Landing: **CHR 5 PIOR 2.**

Configuration 1 (WRI ON, Pitch SAS OFF, Roll SAS OFF):
From south reentry at 3300 feet MSL the VSS was engaged lined up with the runway. (Winds 200v240 22G30) I had to fight the aircraft in pitch all the way down to 20 feet agl. A helpful tool was to note where the bore cross in the windshield was on the ground for desired pitch, and then strive to keep it steady at that point. Nevertheless the nose was porpoising all the way down, and once at 20 feet agl my gain was increased which subconsciously made me climb 10-20 feet. The workload was high, and it was uncomfortable to fight the bounded PIO so close to the ground. Level flight desired criteria was met: **CHR 8 PIOR 4.** The workload became even higher once I started a slow descent for touch down, while I was still in a pitch PIO. The safety pilot disengaged the VSS just prior to touchdown to prevent a hard landing **CHR 10 PIOR 6**. Second attempt (winds 220 20G30) was no different. A small bounded PIO down the runway, and once I started a very slow descent for the landing, the gain became higher the closer we got to the ground, with bigger oscillations. Again the safety pilot disengaged just prior to landing, which would have been firm. Level flight: **CHR 8 PIOR 4**, Landing: **CHR 8 PIOR 4.**

Configuration 4 (WRI OFF, Pitch SAS OFF, Roll SAS OFF):
From south reentry at 3300 feet MSL the VSS was engaged lined up with the runway. (Winds 200v240 22G30) The intense workload with the lateral directional oscillations detracted from my performance in the pitch task. We subsequently ended up flying slightly higher down the runway, with bigger oscillations in pitch. **CHR 9 PIOR 4.** As I started the descent for the landing, I found the sweet spot in pitch where it looked like the aircraft was going very stable and comfortably approached the runway. I was almost sure this was going to be the best landing, when the nose abruptly pitched up, and drove my gains through the roof. Safety pilot took over and did the full stop. **CHR 10 PIOR 5.**

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. TAIL #
Lear 24	N101VS

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION #	B. FLIGHT # / TEST POINTS	C. DATE
HAVE WRIGHT / D2005A	5 / See Below	20 Apr 01
D. FRONT COCKPIT *(Right and Left Seat)*	E. FUEL LOAD	F. JON
Haug & Deppe	5100 lbs	M96J0200
G. REAR COCKPIT *(Rest of Crew)*	H. START UP GR WT / CG	I. WEATHER
Casado & Markofski	13,000 / UNK	Clear, winds 28015
J. TO TIME / SORTIE DURATION	K. CONFIGURATION / LOADING	L. SURFACE CONDITIONS
0745L / 1.4	Gear/20 Flaps/VSS engaged	69 F, PA 2312 ft, Dry Rwy
M. CHASE ACFT / SERIAL NO	N. CHASE CREW	O. CHASE TO TIME / SORTIE TIME
NA		

4. PURPOSE OF FLIGHT / TEST POINTS

The purpose of the flight was to evaluate in flight four different configurations for the Wright Flyer aerodynamic model, using the Veridian Variable Stability Learjet Inflight Simulator (VSSLIS). These configurations were:

Configuration 1: Pitch Stability Augmentation System (SAS) - OFF; Roll SAS – OFF; Warp Rudder Interconnection (WRI) – ON
Configuration 2: Pitch SAS - ON; Roll SAS – OFF; WRI – ON
Configuration 3: Pitch SAS - ON; Roll SAS – ON; WRI – ON
Configuration 4: Pitch SAS - OFF; Roll SAS – OFF; WRI – OFF

The test points were:

1. Tower FlyBy	100 ft AGL / 145 KIAS, Gear down / Flaps 20°
2. Sustained Level Flight over Runway	20 ft AGL / 145 KIAS, Gear down / Flaps 20°
3. Landing	Runway surface / 145 KIAS, Gear down / Flaps 20°

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Aircraft Description: The test item was an in-flight simulation of the aerodynamic math model of the 2003 Wright Flyer. Since the 2003 Wright Flyer has not been constructed yet, the 2003 Wright Flyer math model consists of stability derivatives from wind tunnel tests of the 1903 full-scale replica and stability derivatives from AIAA empirical methods. The 2003 Wright Flyer math model was simulated in the VVSLIS aircraft (tail# N101VS) using MATLAB/SIMULINK software. The stability derivatives and associated state space matrices for the 2003 Wright Flyer math model are shown in Appendix B of the Have Wright test plan.

Overall: Tower flybys were flown with configurations 1, 3, and 4. (Config 2 tower flyby was accomplished on last sortie). All four configurations were flown at least twice during the sustained level flight over the runway and landing tasks. Configurations 2 and 3 were quite comfortable to fly and land. Configurations 1 and 4 were very challenging to fly. Configuration 4 resulted in two abandoned landing tasks with PIO experienced once each in pitch and yaw.

Task Criteria: For the tower flyby and sustained level flight over the runway at 20 feet AGL tasks, the desired performance criterion was level flight for 30 seconds. The adequate performance criterion was level flight for 15 seconds. For the landing task, starting from sustained level flight over the runway at 20 feet AGL, the desired performance criteria was a soft landing within 500 feet of an aimpoint and within 10 feet of centerline. The adequate performance criteria were a firm (or soft) landing within 1000 feet of an aimpoint and within 20 feet of centerline. The safety pilot was responsible for grading landings as soft, firm, or hard.

Configuration 2 (WRI ON, Pitch SAS ON, Roll SAS OFF): This configuration was flown on the flyby line during the last sortie and first in the landing pattern to Palmdale runway 25 on this sortie. Because the aircraft was too heavy to land, the first approach was flown to a go-around. The second and third approaches resulted in landings. There was a definite learning curve for height above ground in the Learjet at Palmdale and for flying power added landings. With this said,

6. RECOMMENDATIONS

R1: Do not implement and fly Configuration 4 on the 2003 Wright Flyer.

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however, I tended to float well past my intended landing point all day and was inclined to accept a long landing over forcing the aircraft down on a spot. I found this configuration to be very comfortable to fly with good pitch and roll control and very little need for yaw inputs. During each approach, I descended gradually to about 20 feet AGL and flew level for approximately 30 seconds prior to calling out an intended landing spot well down the runway and then I gradually descended with a primary goal of a soft landing aligned with the runway and secondary goals of being on the aimpoint and on the centerline. On all three of the level flight at 20 feet AGL tasks I achieved desired performance with a low workload **CHR: 3, PIOR: 1 (x3)**. The first landing was soft, 800 feet long, and about 10 feet off centerline for adequate performance which drove the ratings while the workload was low **CHR: 5, PIOR: 1**. As I sensed that I was floating long again on the second landing, I lightly forced the aircraft down; the landing was firm, ~1200 feet long, and on centerline. This was inadequate performance with a low workload **CHR: 7, PIOR 1**. Overall, I felt this was the most comfortable configuration to fly. I think that task familiarization and currency was a factor in driving performance into the inadequate region and wish that I would have had time and fuel at the end of the sortie to look at performance with this configuration after becoming more comfortable with the landing task and height above touchdown in the simulator aircraft.

Configuration 3 (WRI ON, Pitch SAS ON, Roll SAS ON): This configuration was flown second on the flyby line and second in the landing pattern to Palmdale runway 25. This configuration was comfortable to fly during the descent to the flyby line and on the flyby line itself. Maintaining level flight and correcting pitch errors was relatively easy. However, correcting bank errors and precisely controlling heading was a bit challenging because it seemed to take larger inputs to effect a change in bank and the response seemed slower. Added to that, bank changes resulted in a fairly significant and annoying Dutch roll. For the flyby task, I achieved desired performance with moderate workload. **CHR: 4, PIOR: 1.** During approaches to the runway, the same heaviness in roll was apparent, but not a significant problem for the sustained level flight and landing tasks even though there was a steady crosswind component of about 6 knots. On both of the level flight at 20 feet AGL tasks I achieved desired performance with a low workload **CHR: 3, PIOR: 1 (x2)**. Handling qualities in the landing phase were slightly heavy in roll, but overall, very solid and very predictable. The first landing was firm, 500 feet long, and on centerline. This was adequate performance with a moderate and tolerable pilot workload **CHR: 5, PIOR: 1**. The second landing was soft, just less than 500 feet long, and 5 feet left of the runway centerline. This was desired performance with moderate pilot workload **CHR: 4, PIOR: 1**. Overall, I felt this was a very comfortable configuration to fly.

Configuration 1 (WRI ON, Pitch SAS OFF, Roll SAS OFF): This configuration was flown third on the flyby line and third in the landing pattern to Palmdale runway 25. The workload to maintain level flight was high. After the simulation was engaged at around 700' AGL aligned with the flyby line, the controlled descent to 100' AGL took a lot of compensation. My technique was to keep tight control on pitch by making small singlet inputs every time I saw the start of divergence in pitch. Leveling off at 100 feet AGL was uneventful. I found it to be somewhat difficult to maintain level flight and to correct pitch errors. Due to the workload in pitch, I also found it difficult to correct bank angle errors and heading errors due to a tendency for task fixation. I achieved desired performance but with a high and objectionable workload **CHR: 6, PIOR: 3**. During approaches to the runway, the pitch sensitivity and tendency to diverge was annoying. Small step inputs or singlets were fairly effective to maintain level and controlled flight. Fortunately, roll and yaw were fairly benign factors during these tasks, allowing adequate time to control pitch. On both of the level flight at 20 feet AGL tasks I achieved adequate performance but the workload was very high and objectionable. Considerable compensation was directed toward maintaining control while close to the ground. As it happened, the successful maintenance of control also resulted in adequate performance. Annoying undesirable motions in pitch were observed and they were easily induced **CHR: 8, PIOR: 3 (x2)**. During both landing tasks, adequate performance was barely attained, but again the workload was very high and objectionable. Once again, considerable compensation was directed toward maintaining control while allowing a slight sink rate that would eventually result in a landing. Undesirable divergent pitch motions were again easily induced **CHR: 8, PIOR: 3 (x2)**. Overall, this configuration is flyable and landable, but significant familiarity and training are required to develop and employ effective compensation techniques.

Configuration 4 (WRI OFF, Pitch SAS OFF, Roll SAS OFF): This configuration was flown second on the flyby line and last in the landing pattern to Palmdale runway 25 with due regard for a recommendation from a previous flight to approach operational tasks in Configuration 4 with caution and constant vigilance for task fixation or saturation. As the simulation was engaged at around 700' AGL aligned with the flyby line, the challenges of this configuration became fairly pronounced. The descent to 100' AGL took extensive compensation. My technique was to keep tight control on pitch and yaw by making small singlet inputs every time I saw the start of divergence in either axis. Fortunately, roll control was adequate and required very little attention. It was difficult to maintain level flight, correct pitch and bank errors and maintain heading and centerline over the flyby line. This configuration provided a grossly unsatisfactory capability for precise control. I achieved desired performance with an intolerable workload and experienced undesirable motions in yaw that were easily induced. **CHR: 7, PIOR: 3**. During approaches to the runway, I employed the same technique. On the first level flight at 20 feet AGL task, I encountered a bounded PIO in yaw under normal control. I was able to dampen the PIO with my feet. I questioned my ability

to maintain level flight near the ground, but was able to complete the task and proceed to the landing task. Intense pilot compensation was required to maintain control **CHR: 9, PIOR: 6**. During my second level flight at 20 feet AGL task, I specifically concentrated on keeping tighter control with my feet to null out any perceived sideslip. The learning curve was evident and the extra compensation seemed to help. I achieved desired performance while directing considerable compensation toward maintaining control. Undesirable motions were observed in pitch and in yaw and they were easily induced **CHR: 8, PIO: 3**. Landings were attempted after both level flight at 20 feet AGL tasks. On the first attempt, I had reasonably good success in maintaining control during a gradual descent toward the runway for the landing. Just prior to touchdown at a height of about 3 feet, I began to experience a yaw PIO that appeared to be bounded but too large to land with. The nose of the aircraft was probably only moving about two feet laterally in the PIO, but the motion was uncomfortable while that close to the ground. I abandoned the landing task, initiated a slight pitch up and transferred aircraft control to the safety pilot. Although the task was abandoned, I feel that sufficient control was retained to climb to a more comfortable altitude while dealing with the apparently bounded yaw PIO **CHR: 10, PIOR: 6**. On the second landing attempt, I employed the technique of keeping tighter control with my feet to null sideslip and hopefully prevent yaw PIOs just as I did during the second level flight at 20 feet AGL task. Again the technique appeared to be effective in minimizing undesirable yawing motions and preventing yaw PIOs. However, just prior to touchdown at a height of about 5 feet, I began to experience a pitch PIO that again required abandonment of the landing task. I initiated a slight pitch up and transferred aircraft control to the safety pilot. I do not know if the PIO was bounded or not, but I suspect the nose of the aircraft was moving about three feet vertically during the PIO when I abandoned the task. I found the pitch PIO to be very uncomfortable while that close to the ground and am not totally confident that adequate control was retained to safely climb away from the ground. In addition, I find it ironic and noteworthy that I specifically concentrated on tighter control of yaw during this pass and experienced a pitch PIO while doing so **CHR: 10, PIOR: 6**. Overall, this configuration is flyable and is probably landable, but on both of my landing attempts, I experienced PIOs just prior to touchdown (one in yaw, one in pitch). A very high degree of compensation is required to effectively control the pitch and yaw axes. While in control, it may appear that things are going very well with only small excursions in any axis and small control inputs required. But in an instant, it can turn ugly with large excursions and responding large inputs in the pitch and yaw axes, pilot task saturation, and loss of control. **R1: Do not implement and fly Configuration 4 on the 2003 Wright Flyer.**

DAILY/INITIAL FLIGHT TEST REPORT

1. AIRCRAFT TYPE	2. SERIAL NUMBER
Lear-24	N101VS

3. CONDITIONS RELATIVE TO TEST

A. PROJECT / MISSION NO HAVE WRIGHT	B. FLIGHT NO / DATA POINT 3/Test Flight	C. DATE 20 Apr 01
D. FRONT COCKPIT *(Right Seat)* Jansen/Deppe	E. FUEL LOAD 5100 lbs	F. JON M96J0200
G. REAR COCKPIT *(Jump Seat)* Jorris/Markofski	H. START UP GR WT / CG 13000/Unk	I. WEATHER Clear
J. TO TIME / SORTIE TIME 1030 (L) / 1.5	K. CONFIGURATION / LOADING 20% Flaps/Gear Down	L. SURFACE CONDITIONS Dry, winds 200-260/010
M. CHASE ACFT / TAIL NO N/A	N. CHASE CREW N/A	O. CHASE TO TIME / SORTIE TIME N/A

4. PURPOSE OF FLIGHT / TEST POINTS

The purpose of the flight was to evaluate approach and landing of four different configurations for the Wright Flyer aerodynamic model, using the Veridian Variable Stability Learjet Inflight Simulator (VSSLIS). These configurations were:

Configuration 1: Pitch Stability Augmentation System (SAS) - OFF; Roll SAS – OFF; Wing Rudder Interconnection (WRI) – ON

Configuration 2: Pitch SAS - ON; Roll SAS – OFF; WRI – ON

Configuration 3: Pitch SAS - ON; Roll SAS – ON; WRI – ON

Configuration 4: Pitch SAS - OFF; Roll SAS – OFF; WRI – OFF

The test points were:

1. Tower flyby with configuration 4
2. Four low approaches, without touchdown, in each priority rated configuration
3. Eight low approaches followed by touchdown in (2 per priority rated configuration).

5. RESULTS OF TESTS *(Continue on reverse if needed)*

Aircraft Description: The test aircraft was the VSSLIS.
Overall Results: Pilot Rankings: in priority order.

5. Configuration 2
6. Configuration 3
7. Configuration 1
8. Configuration 4

Tower Flyby: I flew one tower flyby for a warm-up up prior to approaches and landings. I chose configuration 4 having flown all configurations down the flyby line previously. I found the aircraft surprisingly easy to fly using a high bandwidth technique in both pitch and yaw. The techniques that worked best for me were step inputs to arrest divergent rates or to make attitude changes then maintaining the new attitude with high bandwidth inputs (2-3 per second) in both fore and aft stick and left and right rudder. Literally, it was like being your own pitch and yaw damper. I could not achieve the high bandwidth inputs with the rudders without putting both feet completely on the rudder pedals. By resting my heels on the floor, I couldn't move the rudder pedals fast enough and the aircraft would become uncontrollable in yaw. During the high bandwidth inputs I tried not to let the pitch or yaw get outside of +/- 2 degrees. This worked well. I was able to achieve desired criteria with a moderate to high workload. **CHR-5, PIOR-3**

7. Comments:

It is possible to go open loop in pitch control for configs 2 and 3 without sacrificing performance.

In config 1 high bandwidth inputs keeping pitch attitude within +/- 2 degrees of desired attitude works well.

The high bandwidth inputs made the aircraft more resistant to gust deviations.

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Low Approach followed by a climbout (Config 2): I found this configuration easy to fly for the 20-foot approach task. Pitch response was more sluggish than with the Pitch SAS off, however, the response was adequate for the task. While I didn't go open loop during the task, I could have easily done so without sacrificing performance. This would be something worth mentioning to Fred (see comments). Another nice effect of the pitch SAS was its resistance to deviations from gusts which were very noticeable in the configurations with the pitch SAS off. I achieved adequate performance for the low approach due to a slight climb during the task. I also executed a go around simulating a takeoff condition. I don't think there is much benefit to doing this, because once you've reached this point, you've already found the aircraft's handling characteristics, unlike Fred who will feel the characteristics for the first time on takeoff. Anyhow, the go-around was easy and uneventful. **CHR-4, PIOR-1**

Low Approach followed by a climbout (Config 3): I found this configuration easy to fly for the 20-foot approach task. Pitch response was more sluggish than with the Pitch SAS off, however, the response was adequate for the task. While I didn't go open loop during the task, I could have easily done so without sacrificing performance. This would be something worth mentioning to Fred (see comments). Another nice effect of the pitch SAS was its resistance to deviations from gusts which were very noticeable in the configurations with the pitch SAS off. I achieved desired performance for the low approach. I also executed a go around simulating a takeoff condition. I don't think there is much benefit to doing this, because once you've reached this point, you've already found the aircraft's handling characteristics, unlike Fred who will feel the characteristics for the first time on takeoff. Anyhow, the go-around was easy and uneventful. **CHR-3, PIOR-1**

Low Approach followed by a climbout (Config 1): I found this configuration more difficult to fly for the 20-foot approach task than the previous 2. Pitch response was very sensitive, too much for the task. I could not go open loop in pitch control without losing aircraft control. This would be something worth mentioning to Fred (see comments). Deviations from gusts were very noticeable, requiring step inputs to arrest the resulting pitch rate, followed by high bandwidth inputs to maintain the new pitch attitude. I did find however that the high bandwidth inputs made the aircraft more resistant to gust deviations. I think this was due to the high bandwidth technique actually catching any pitch divergence prior to it happening. Without the high bandwidth technique, pilot reaction time and associated large inputs to correct for gust deviations causes their effects to be more pronounced. This would be something worth mentioning to Fred (see comments). I achieved desired performance for the low approach. However, workload drove my CHR. I also executed a go around simulating a takeoff condition. This required a step input to set the new pitch attitude, followed by high bandwidth to maintain it. **CHR-6, PIOR-3**

Low Approach followed by a climbout (Config 4):. Pitch response was very sensitive, too much for the task. I could not go open loop in pitch control without losing aircraft control. This would be something worth mentioning to Fred (see comments). Yaw response was very similar to pitch response. This configuration flew very similar to a glider with no airspeed bleed off. Deviations from gusts were very noticeable, requiring step inputs to arrest the resulting pitch and yaw rates, followed by high bandwidth inputs to maintain the new pitch and yaw attitudes. I did find however that the high bandwidth inputs made the aircraft more resistant to gust deviations. I think this was due to the high bandwidth technique actually catching any pitch and yaw divergences prior to them happening. Without the high bandwidth technique, pilot reaction time and associated large inputs to correct for gust deviations causes their effects to be more pronounced. This would be something worth mentioning to Fred (see comments). I achieved desired performance for the low approach. However, workload drove my CHR. I also executed a go around simulating a takeoff condition. This required a step input to set the new pitch attitude, followed by high bandwidth to maintain it. **CHR-6, PIOR-3.**

Landings: I executed 2 landings in each configuration for a total of 8 landings. Each was preceded by another 20 foot sustained level flight task. The comments did not vary from the comments above; therefore I will only provide CHR and PIOR for the 20-foot task. The following discussion pertains to the landing phase from the point I committed out of the 20-foot level flight task.

Landings (Config 2): 20-foot level flight – **CHR4, PIOR2**. I executed 2 landings in this configuration. I found pitch attitude easy to change and hold with a minimum workload. Once the initial descent was established I found it very easy to go open loop in pitch because the pitch attitude stays where you put it. The only time I couldn't go open loop was when gusts were present. After the initial descent attitude was established and I went open loop, I went closed loop one more time to command pitch up to slow the descent. Once this new pitch attitude was established, I could go open loop all the way to touchdown (provided no gusts present). Also, I executed the landing phase completely closed loop and high bandwidth. While the results were similar, the workload was just slightly higher. This would be a good technique for a pilot who likes to retain control throughout the task or during gusty conditions. My first landing was within desired criteria except the landing was FIRM dictating a **CHR-5, PIOR-2.** The second landing met desired criteria dictating a **CHR-4, PIOR-2**

Landings (Config 3): 20-foot level flight – **CHR4, PIOR2**. I executed 2 landings in this configuration. Both were very similar if not imperceptibly different from config 2. I found pitch attitude easy to change and hold with a minimum workload. Once the initial descent was established I found it very easy to go open loop in pitch because the pitch attitude stays where you put it. The only time I couldn't go open loop was when gusts were present. After the initial descent attitude was established and I went open loop, I went closed loop one more time to command pitch up to slow the descent. Once this new pitch attitude was established, I could go open loop all the way to touchdown (provided no gusts present). Also, I executed the landing phase completely closed loop and high bandwidth. While the results were similar, the workload was just slightly higher. This would be a good technique for a pilot who likes to retain control throughout the task or during gusty conditions. Both landings were within desired criteria. **CHR-4, PIOR-2 for both.**

Landings (Config 1): 20-foot level flight – **CHR6, PIOR3**. I executed 2 landings in this configuration. I found pitch attitude moderately

difficult to change with step inputs and hold with high bandwidth inputs. I could not go open loop in pitch because the pitch attitude diverges so quickly. Actively controlling a smooth touchdown in this configuration is very difficult. You almost take what you can get. The higher bandwidth you get closer to touchdown, with smaller amplitude inputs, seemed to smooth out the landings. However, I never achieved desired criteria due to firm landings. My first landing workload was high and was within desired criteria except the landing was HARD dictating a **CHR-7, PIOR-3.** The second landing met desired criteria, except for the FIRM landing, dictating a **CHR-6, PIOR-3.**

Landings (Config 1): 20-foot level flight – **CHR6, PIOR3**. I executed 2 landings in this configuration. I found pitch and yaw attitudes moderately difficult to change with step inputs and hold with high bandwidth inputs. I could not go open loop in pitch or yaw because the pitch and yaw attitudes diverge so quickly. Actively controlling a smooth touchdown in this configuration is very difficult. In fact, this was by far the hardest configuration to land. You almost take what you can get. By first controlling yaw with high bandwidth inputs, the workload was dramatically decreased. The higher bandwidth you get closer to touchdown, with smaller amplitude inputs, seemed to smooth out the landings. However, I never achieved desired criteria due to HARD landings. My first landing workload was high and was within desired criteria (lucky) **CHR-6, PIOR-3.** The second landing workload was higher just prior to touchdown and did not meet desired criteria due to the HARD landing, dictating a **CHR-7, PIOR-3.**

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APPENDIX I – RATING SCALES

COOPER-HARPER RATING SCALE

PILOT IN-THE-LOOP OSCILLATION SCALE

ANALOG RATING SCALES

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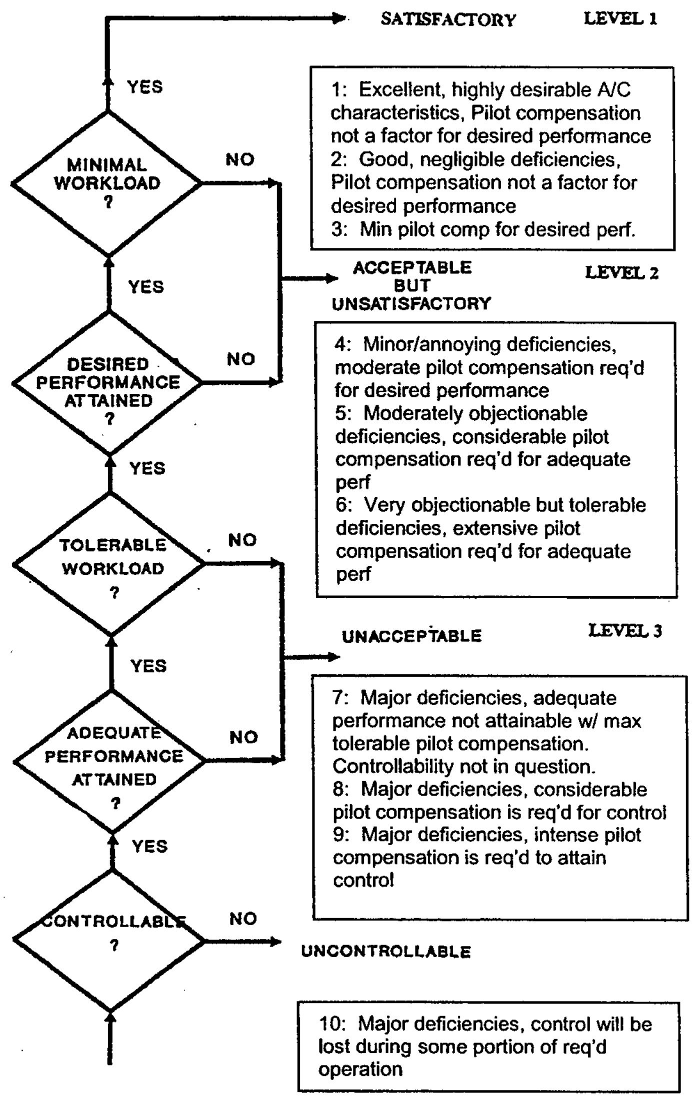

Figure I1 – Cooper-Harper Rating Scale

PIO RATING

First Question: "Did I experience PIO?"

No:

Did any undesirable motion occur? <u>Rating</u>

No --1

Yes

Tend to occur? ----------------------------2

Easily induced? ---------------------------3

Yes:

While attempting abrupt or tight control?

Motion bounded? -----------------------4

Motion divergent? ----------------------5

While attempting normal control? ---------------6

Note: Undesirable motion must occur as a response to pilot control

Figure I2 – Pilot In-The-Loop Oscillation (PIO) Rating Scale

ANALOG SCALES FOR LOW BANDWIDTH EVALUATION OF PITCH RESPONSE:

Note: Numbers on the analog scales represent configuration numbers.
Configuration 1 = pitch SAS **off**, roll SAS **off**, WRI **on**
Configuration 2 = pitch SAS **on**, roll SAS **off**, WRI **on**
Configuration 3 = pitch SAS **on**, roll SAS **on**, WRI **on**
Configuration 4 = pitch SAS **off**, roll SAS **off**, WRI **off**

Initial delay in pitch response:

Pilot A none |-----1-4------------------------------------|---------2-3--| gross delay
Pilot B none |----------1-2-3-4---------------------------|---| gross delay
Pilot C none |---------1-2-3-4----------------------------|---| gross delay

Onset of pitch response:

Pilot A very smooth |------------------------------------2-3-------|------------------------------------1-4---------| too abrupt
Pilot B very smooth |----------------1-2-3-4-----------------------|---| too abrupt
Pilot C very smooth |---------2-3-------------1-4------------------|---| too abrupt

Speed of pitch response (following initial delay and onset):

Just Right

Pilot A much too fast |----------1-4---------------------------------|---------------2-3-------------------------------| extremely sluggish
Pilot B much too fast |---------1-4---------------------------------|---2-3---| extremely sluggish
Pilot C much too fast |-----------------1-4-------------------------|------------------2-3----------------------------| extremely sluggish

Initial tendency to overshoot or undershoot pitch attitude:

None

Pilot A large undershoots |---|-----------------2-3----------------1-4--------| large overshoots
Pilot B large undershoots |---1-|4--2-3---| large overshoots
Pilot C large undershoots |--2-3|----------------1-4------------------------------| large overshoots

Final tendency to overshoot or undershoot pitch attitude:

None

Pilot A large undershoots |----------------------------1-4------------2-3|--| large overshoots
Pilot B large undershoots |---1-|4--2-3---| large overshoots
Pilot C large undershoots |--2-3|---1-4--| large overshoots

Predictability of pitch response:

Pilot A completely predictable |------------------------------2-3-------------|--------------------------1-4------------------| absolutely unpredictable
Pilot B completely predictable |-------------------------2-3-------------------|------------------------1-4--------------------| absolutely unpredictable
Pilot C completely predictable |--------------------2-3-------------------------|------1-4--------------------------------------| absolutely unpredictable

Sensitivity of pitch response:

Just Right

Pilot A extremely sensitive |----1-4--|-------------2-3---------------------------------| extremely sluggish
Pilot B extremely sensitive |-----------------1-4---------------------------|--2-3---| extremely sluggish
Pilot C extremely sensitive |------------1-4--------------------------------|-----------------2-3------------------------------| extremely sluggish

Ability to arrest pitch rate:

Pilot A very easy |------------------2-3---------------------------|---------------------1-4----------------------| very hard
Pilot B very easy |-------------------2-3--------------------------|--------------------1-4-----------------------| very hard
Pilot C very easy |-------------------------2-3--------------------|---------------------------------1-4----------| very hard

Linearity of pitch response:

Linear

Pilot A small to large |--1-4---------------------------------------2-3|--| large to small
Pilot B small to large |--1-4---|--2-3---| large to small
Pilot C small to large |---1-4--------------------------------------2-3|--| large to small

ANALOG SCALES FOR LOW BANDWIDTH EVALUATION OF PITCH RESPONSE (CONT'D)

Ability to change pitch attitude rapidly:

Pilot A very easy |----1-4--------------------------------------|----------2-3-------------------------------| very hard
Pilot B very easy |---2-3-|--------------------------------1-4-----------| very hard
Pilot C very easy |--------------------1-4------------------------|-------------------2-3-----------------------| very hard

Ability to change pitch attitude precisely:

Pilot A very easy |---------------2-3-----------------------------|-------------------------------------1-4------| very hard
Pilot B very easy |-----------------2-3---------------------------|--1-4---| very hard
Pilot C very easy |---------2-3-----------------------------------|----------------------------1-4----------------| very hard

Perception of control stick dynamics:

Pilot A very comfortable |------------------------------------1-4-2-3---|---| very annoying
Pilot B very comfortable |---------1-4---2-3-----------------------------|---| very annoying
Pilot C very comfortable |-----1-4---2-3---------------------------------|---| very annoying

Workload in Pitch:

Pilot A very low |-----------------------------------2-3--------|---------------------------------1-4----------| very high
Pilot B very low |-----------------------2-3-------------------|-----------------------------1-4---------------| very high
Pilot C very low |-----------------------------2-3-------------|---------------------------------1-4----------| very high

ANALOG SCALES FOR LOW BANDWIDTH EVALUATION OF LAT-DIR RESPONSE:

Note: Numbers on the analog scales represent configuration numbers.
Configuration 1 = pitch SAS **off**, roll SAS **off**, WRI **on**
Configuration 2 = pitch SAS **on**, roll SAS **off**, WRI **on**
Configuration 3 = pitch SAS **on**, roll SAS **on**, WRI **on**
Configuration 4 = pitch SAS **off**, roll SAS **off**, WRI **off**

Initial delay in roll response:

```
Pilot A   none         |-------------------------------------------|-3--4-------------------------1-2---------|  gross delay
Pilot B   none         |-------------------------------------------|-----------------------1-2-3-4------------|  gross delay
Pilot C   none         |-------------------------------------------|---------------3-1-2--4-------------------|  gross delay

Pilot A   very smooth  |--------1-2---------------------------3--4|-------------------------------------------|  too abrupt
Pilot B   very smooth  |-------4----1-2-3-------------------------|-------------------------------------------|  too abrupt
Pilot C   very smooth  |-----------1-2--3-------------4------------|-------------------------------------------|  too abrupt
```

Onset of roll response:

```
Pilot A   very smooth  |--------1-2---------------------------3--4|-------------------------------------------|  too abrupt
Pilot B   very smooth  |-------4----1-2-3-------------------------|-------------------------------------------|  too abrupt
Pilot C   very smooth  |-----------1-2--3-------------4------------|-------------------------------------------|  too abrupt
```

Speed of roll response (following initial delay and onset):

```
                                                          Just Right
Pilot A   much too fast  |-------------------------------------------|---3--4-----------------------1-2---------|  extremely sluggish
Pilot B   much too fast  |-------------------------------------------|------------------3---1-2----4-------------|  extremely sluggish
Pilot C   much too fast  |-------------------------------------------|-----------------------1-2---3-4-----------|  extremely sluggish
```

Tendency to overshoot or undershoot bank attitude:

```
                                                             None
Pilot A   large undershoots  |----------------------------------------1-|2-3-4------------------------------------|  large overshoots
Pilot B   large undershoots  |----------------------------------------1|-2-3-4------------------------------------|  large overshoots
Pilot C   large undershoots  |--------------------4-------------------1-|2-3--------------------------------------|  large overshoots
```

Predictability of roll response to roll control:

```
Pilot A  completely predictable |--------------------------------------3--|------4----1-2------------------------------|  absolutely unpredictable
Pilot B  completely predictable |---------------------------3--------------|-----------------------1-2--------------4-----|  absolutely unpredictable
Pilot C  completely predictable |-----------------1-2---3-----------------|---------4-----------------------------------|  absolutely unpredictable
```

Sensitivity of roll response to roll control:

```
                                                            Just Right
Pilot A   extremely sensitive |-----------------------------------------|3---4---------------------------1-2---------|  extremely sluggish
Pilot B   extremely sensitive |-----------------------------------------|----------------------1-2--3---------4------|  extremely sluggish
Pilot C   extremely sensitive |-----------------------------------------|---4----------------1-2---3-----------------|  extremely sluggish
```

Ability to change bank attitude precisely:

```
Pilot A   very easy   |-------------1-2-------3---------4---------|-------------------------------------------|  very hard
Pilot B   very easy   |----------------------------3-------------|------------------------1-2----4-----------|  very hard
Pilot C   very easy   |---------------------------4--------------|----------1-2-3----------------------------|  very hard
```

Linearity of roll response:

```
                                                            Linear
Pilot A   small to large   |------------------------------------3------|-----------------------4---1-2------------|  large to small
Pilot B   small to large   |-------------------4----1-2----------------|---3----------------------------------------|  large to small
Pilot C   small to large   |---------------------------------------1-2|-3-4--------------------------------------|  large to small
```

ANALOG SCALES FOR LOW BANDWIDTH EVALUATION OF LAT-DIR RESPONSE (CONT'D):

Yaw due to roll:

```
                                                       None
Pilot A   dramatic adverse   |---------------------4-------1-2-----3------|---------------------------------------------|  dramatic proverse
Pilot B   dramatic adverse   |------------4----1-2---3--------------------|---------------------------------------------|  dramatic proverse
Pilot C   dramatic adverse   |-----4--3-------------------1-2-------------|---------------------------------------------|  dramatic proverse
```

Tendency to overshoot or undershoot heading:

```
                                                       None
Pilot A   large undershoots  |------------------------------------------3|---------1-2-------4------------------------|  large overshoots
Pilot B   large undershoots  |--------------------------------------------|---------------3------1-2---------4--------|  large overshoots
Pilot C   large undershoots  |-------------------------------------1-2----|-------------------------------------3-4---|  large overshoots
```

Predictability of directional response to roll control:

```
Pilot A  completely predictable |-----------------------------------3--------1|-2-------------------4---------------------|  absolutely unpredictable
Pilot B  completely predictable |--------------------------------3------------|-------1-2--------------------4-------------|  absolutely unpredictable
Pilot C  completely predictable |-------------------1-2-----------------------|---------3------------------4---------------|  absolutely unpredictable
```

Perception of roll control stick dynamics:

```
Pilot A   very comfortable   |----------------------------------1-4-2-3----|--------------------------------------------|  very annoying
Pilot B   very comfortable   |--------------3---------1-2------------------4|-------------------------------------------|  very annoying
Pilot C   very comfortable   |--------1-2-------3--4-----------------------|--------------------------------------------|  very annoying
```

Ability to arrest roll rate:

```
Pilot A   very easy          |------1-2------------------4-------3----------|--------------------------------------------|  very hard
Pilot B   very easy          |------------------------------------3------------|-------------------1-2---------4---------|  very hard
Pilot C   very easy          |----------------------------------------------|------------------1-2-----3-------4-------|  very hard
```

Ability to arrest yaw rate:

```
Pilot A   very easy          |--------------------------------------3------1|-2----4-----------------------------------|  very hard
Pilot B   very easy          |--------------------------------------3-------1-|2----------------------------4-----------|  very hard
Pilot C   very easy          |---------------------------------------1-2-------|------------3--------------4--------------|  very hard
```

ANALOG SCALES FOR HIGH BANDWIDTH EVALUATION OF PITCH:

Note: Numbers on the analog scales represent configuration numbers.
Configuration 1 = pitch SAS **off**, roll SAS **off**, WRI **on**
Configuration 2 = pitch SAS **on**, roll SAS **off**, WRI **on**
Configuration 3 = pitch SAS **on**, roll SAS **on**, WRI **on**
Configuration 4 = pitch SAS **off**, roll SAS **off**, WRI **off**

Initial delay in pitch response:

Pilot A none |--------1-4-------------------------------|-------2-3--------------------------------| gross delay
Pilot B none |-----------1-4---2-3-------------------------|--| gross delay
Pilot C none |--|------1-4-2-3------------------------------| gross delay

Onset of pitch response:

Pilot A very smooth |----------------------------------2-3------|-------------------------------1-4----------| too abrupt
Pilot B very smooth |---------------2-3--------------------1-4--|--| too abrupt
Pilot C very smooth |---------------2-3-----------1-4-----------|--| too abrupt

Speed of pitch response (following initial delay and onset):

Just Right

Pilot A much too fast |---------1-4--------------------------------|-----------2-3-------------------------------| extremely sluggish
Pilot B much too fast |-----------------1-4------------------------|--------------------2-3----------------------| extremely sluggish
Pilot C much too fast |-----------------------1-4------------------|-----------------2-3-------------------------| extremely sluggish

Initial tendency to overshoot or undershoot pitch attitude:

None

Pilot A large undershoots |--------------------------------2-3------|-------------------------------1-4------------| large overshoots
Pilot B large undershoots |---2|-3-----------------1-4----------------------| large overshoots
Pilot C large undershoots |----------------------------------2-3-----|---------------------------1-4-----------------| large overshoots

Final tendency to overshoot or undershoot pitch attitude:

None

Pilot A large undershoots |---------------1-4------------------2-3--|---| large overshoots
Pilot B large undershoots |--2-|3-------1-4---------------------------------| large overshoots
Pilot C large undershoots |-----------------------------------2-3----|---------------------1-4----------------------| large overshoots

Predictability of pitch response:

Pilot A completely predictable |------------------------------2-3---------|------------------------1-4-------------------| absolutely unpredictable
Pilot B completely predictable |---------------------2-3------------------|--------------------1-4----------------------| absolutely unpredictable
Pilot C completely predictable |--------------------2-3-------------------|------------------------1-4-------------------| absolutely unpredictable

Sensitivity of pitch response:

Just Right

Pilot A extremely sensitive |-----------1-4------------------------------|--------2-3----------------------------------| extremely sluggish
Pilot B extremely sensitive |--------------------1-4----------------------|-2-3--| extremely sluggish
Pilot C extremely sensitive |------------------1-4------------------------|-----------------2-3------------------------| extremely sluggish

Linearity of pitch response:

Linear

Pilot A small to large |-------1-4-------------------------------------|-----------2-3-------------------------------| large to small
Pilot B small to large |--------------1-4--------------------------2-3|---| large to small
Pilot C small to large |-------------1-4-------------------------2-3--|---| large to small

Ability to change pitch rapidly:

Pilot A very easy |-------------1-4-------------------------------|-----2-3--------------------------------------| very hard
Pilot B very easy |-------------------2-3--------------------------|-------------------------1-4------------------| very hard
Pilot C very easy |-----------------1-4----------------------------|-------------2-3-----------------------------| very hard

ANALOG SCALES FOR HIGH BANDWIDTH EVALUATION OF PITCH (CONT'D):

Ability to change pitch attitude precisely:

Pilot A very easy |------------------------------2-3-------------|--------------------------1-4---------------| very hard
Pilot B very easy |-------------------------2-3------------------|-------------------------1-4-----------------| very hard
Pilot C very easy |----------------------------2-3---------------|------------------------------1-4------------| very hard

Perception of control stick dynamics:

Pilot A very comfortable |---------------------------------2-3-1-4------|---| very annoying
Pilot B very comfortable |--------------------------2-3----1-4----------|---| very annoying
Pilot C very comfortable |---1-4-|-2-3--| very annoying

ANALOG SCALES FOR HIGH BANDWIDTH EVALUATION OF BANK:

Note: Numbers on the analog scales represent configuration numbers.
Configuration 1 = pitch SAS **off**, roll SAS **off**, WRI **on**
Configuration 2 = pitch SAS **on**, roll SAS **off**, WRI **on**
Configuration 3 = pitch SAS **on**, roll SAS **on**, WRI **on**
Configuration 4 = pitch SAS **off**, roll SAS **off**, WRI **off**

Initial delay in roll response:

```
Pilot A   none           |-------------------------------------------3--|4-------------------------------1-2---------|   gross delay
Pilot B   none           |----------------------------------------------|----------------------1-2-----3--4---------|   gross delay
Pilot C   none           |--1-2------3-------4------------------------------|--------------------------------------------|   gross delay

Pilot A   very smooth    |------------------1-2----------------------4---|-3--------------------------------------------|   too abrupt
Pilot B   very smooth    |---------1-2-------------------------------------|----------------------------------------------|   too abrupt
Pilot C   very smooth    |--------1-2-3--4----------------------------------|----------------------------------------------|   too abrupt
```

Onset of roll response:

```
Pilot A   very smooth    |------------------1-2----------------------4---|-3--------------------------------------------|   too abrupt
Pilot B   very smooth    |---------1-2-------------------------------------|----------------------------------------------|   too abrupt
Pilot C   very smooth    |--------1-2-3--4----------------------------------|----------------------------------------------|   too abrupt
```

Speed of roll response (following initial delay and onset):

```
                                                       Just Right
Pilot A   much too fast        |----------------------------------------------3-|-4-----------------------------1-2----------|   extremely sluggish
Pilot B   much too fast        |------------------------------------------------|--------------------4----------1-2--------|   extremely sluggish
Pilot C   much too fast        |------------------------------------------------|--------------------1-2------3-4----------|   extremely sluggish
```

Tendency to overshoot or undershoot bank attitude:

```
                                                        None
Pilot A   large undershoots  |-------------------------------------------1-2|----3-4---------------------------------------|   large overshoots
Pilot B   large undershoots  |---------------------------------------------1-|2----------------------------------------------|   large overshoots
Pilot C   large undershoots  |-------------------------------------------1-2-|-3----4-------------------------------------|   large overshoots
```

Predictability of roll response to roll control:

```
Pilot A  completely predictable |----------------------------------------4------|----3--1-2---------------------------------|   absolutely unpredictable
Pilot B  completely predictable |--------------1-2--------------------------------|--------------------------------------------|   absolutely unpredictable
Pilot C  completely predictable |---------------------1-2--------3---------------|--------4-----------------------------------|   absolutely unpredictable
```

Sensitivity of roll response to roll control:

```
                                                        Just Right
Pilot A   extremely sensitive |--------------------------------------------4|--3---------------------------1-2-----------|   extremely sluggish
Pilot B   extremely sensitive |----------------------------------------------|----------------------1-2------------------|   extremely sluggish
Pilot C   extremely sensitive |----------------------------------------------|-----------1-2-----4-----3----------------|   extremely sluggish
```

Ability to change bank attitude precisely:

```
Pilot A   very easy      |---------------------1-2-------------------4---|3--------------------------------------------|   very hard
Pilot B   very easy      |---------------1-2--------------------------------|----------------------------------------------|   very hard
Pilot C   very easy      |-------------------------1-2------------3-----|----------------4----------------------------|   very hard
```

Linearity of roll response:

```
                                                        Linear
Pilot A   small to large     |-----------------------------------------------|3----------------------4----1-2-------------|   large to small
Pilot B   small to large     |------------------------------------------1-2-|----------------------------------------------|   large to small
Pilot C   small to large     |-------------------------------------4----1-2-|-3-------------------------------------------|   large to small
```

ANALOG SCALES FOR HIGH BANDWIDTH EVALUATION OF BANK (CONT'D):

Yaw due to roll:

None

Pilot A dramatic adverse |-----------------4------3--------1-2----------|--| dramatic proverse
Pilot B dramatic adverse |------------1-2-------------------------------|--| dramatic proverse
Pilot C dramatic adverse |----------4-------------------------3--------1|-2---| dramatic proverse

Tendency to overshoot or undershoot heading:

None

Pilot A large undershoots |-------------------------------------1-2-----|--3----4-------------------------------------| large overshoots
Pilot B large undershoots |---|------------------1-2-----------------------| large overshoots
Pilot C large undershoots |---1-2-|-------3------4------------------------------| large overshoots

Predictability of directional response to roll control:

Pilot A completely predictable |-----------------------------------4---------|-----3--1-2---------------------------------| absolutely unpredictable
Pilot B completely predictable |---|--| absolutely unpredictable
Pilot C completely predictable |---------1-2---------------------------------|--------------3---------4-------------------| absolutely unpredictable

Perception of roll control stick dynamics:

Pilot A very comfortable |---------------------------------3-1-2-4----|--| very annoying
Pilot B very comfortable |-----------3--------1-2-----------------4---|--| very annoying
Pilot C very comfortable |-------4------1-2------3--------------------|--| very annoying

ANALOG SCALES FOR 100' AGL LEVEL FLIGHT:

Note: Numbers on the analog scales represent configuration numbers.
Configuration 1 = pitch SAS **off**, roll SAS **off**, WRI **on**
Configuration 2 = pitch SAS **on**, roll SAS **off**, WRI **on**
Configuration 3 = pitch SAS **on**, roll SAS **on**, WRI **on**
Configuration 4 = pitch SAS **off**, roll SAS **off**, WRI **off**

Ability to maintain level flight:

Pilot A	very easy	|---------------2--3-----------------1- 4 --|--|	very difficult
Pilot B	very easy	|3 2 --|---------- 1 -------------- 4 -------------|	very difficult
Pilot C	very easy	|----- 2 ----------------- 3 ----------------|-------- 1 --------------- 4 --------------|	very difficult

Ability to correct pitch errors:

Pilot A	very easy	|----------------------------------2-3--------|-1- 4 --------------------------------------|	very difficult
Pilot B	very easy	|- 3 2 --|---------------------- 1 4 -----------------|	very difficult
Pilot C	very easy	|------------------------------------ 2 3 ------|------- 1-------- 4 -------------------------|	very difficult

Ability to correct bank angle errors:

Pilot A	very easy	|----------------------2--3-----1-------- 4 |--|	very difficult
Pilot B	very easy	|- 3 ---------------------- 2 – 1 -----------|--- 4 --|	very difficult
Pilot C	very easy	|------------------------------ 2 3 --------- 1 ------------------------------- 4 ---------|	very difficult

Ability to correct heading errors:

Pilot A	very easy	|----------------------------------2----------|- 4 ------1-----3--------------------------|	very difficult
Pilot B	very easy	|- 3 --------- 2 – 1 -----------------------------|-------------------- 4 ---------------------|	very difficult
Pilot C	very easy	|--------------------- 3 -------------- 2 ---|-------- 1 ---------- 4 ----------------------|	very difficult

Ability to go around from low approach:

Pilot A	very easy	|---------------------------2-3---1--- 4-----|---|	very difficult
Pilot B	very easy	|- 3 – 2 -------------------------------------|---- 1 --- 4 ---------------------------------|	very difficult
Pilot C	very easy	|----------- 3 --2 1 --- 4 ------------------|---|	very difficult

Linearity of response to control relationship:

linear

Pilot A	small to large	|------- 4 --1------------------------2--3-|--|	large to small
Pilot B	small to large	|--- 4 – 1 ---------------------------- 2 -- 3 ---|	large to small
Pilot C	small to large	|-------------------------- 14 -------- 2 --- 3 --|	large to small

Sensitivity to pilot bandwidth:

Just Right

Pilot A	insensitive	|---------------------------2--3------------|--------------------------1---- 4 --------|	extremely sensitive
Pilot B	insensitive	|----------------- 3 2 --------------------|-- 1 --------- 4 ----------------------------|	extremely sensitive
Pilot C	insensitive	|---------------------------------- 132-----|------- 4 -----------------------------------|	extremely sensitive

Necessity to open loop to perform task:

Pilot A	not required	|----- 4 --1---------------------2--3--------|--|	essential for success
Pilot B	not required	|------------------ 1234 --------------------|--|	essential for success
Pilot C	not required	|- 2 -- 3 ----- 1 -------------- 4 -----------|--|	essential for success

Overall precision of control:

Linear

Pilot A	perfect	|-------------------------------2--3----------|--1---- 4 ---------------------------------|	grossly unsatisfactory
Pilot B	perfect	|----------------- 3 – 2 ---------------------|------------- 1 -----------------------4 ---|	grossly unsatisfactory
Pilot C	perfect	|------------------------------------ 32 --------|---- 1 ------------------------ 4 ---------|	grossly unsatisfactory

Perception of control stick dynamics:

Pilot A	very comfortable	|------------------3-2-1-4--------------------|--|	very annoying
Pilot B	very comfortable	|---------------1234 --------------------------|--|	very annoying
Pilot C	very comfortable	|-32 1 -4--------------------------------------|--|	very annoying

ANALOG SCALES FOR 20' AGL LEVEL FLIGHT & LANDING:

Note: Numbers on the analog scales represent configuration numbers.
Configuration 1 = pitch SAS **off**, roll SAS **off**, WRI **on**
Configuration 2 = pitch SAS **on**, roll SAS **off**, WRI **on**
Configuration 3 = pitch SAS **on**, roll SAS **on**, WRI **on**
Configuration 4 = pitch SAS **off**, roll SAS **off**, WRI **off**

Ability to maintain level flight:

Pilot A very easy |---------------------- 3 ---------------------|---- 2 – 1 – 4 ----------------------------| very difficult
Pilot B very easy |--- 3 – 2 ------------------------------------|-------------------- 1 ----- 4 --------------| very difficult
Pilot C very easy |------ 3--- 2---------------------------------|-------------- 1 ----------------- 4 --------| very difficult

Ability to correct pitch errors:

Pilot A very easy |------------ 3 ----------- 2 -----------------|------ 4 - 1 --------------------------------| very difficult
Pilot B very easy |--- 3 2 --------------------------------------|--------------------- 1 ---- 4 -------------| very difficult
Pilot C very easy |------- 3 --- 2 ------------------------------|------------------ 1 ------------ 4 --------| very difficult

Ability to correct bank angle errors:

Pilot A very easy |-------------------------------------- 3- 2 1-|--- 4 --| very difficult
Pilot B very easy |- 3 --|- 2 ----1 ----------------------- 4 --------| very difficult
Pilot C very easy |----------- 2 ---------------------------- 1---|---- 3 -------------------------- 4 --------| very difficult

Ability to correct heading errors:

Pilot A very easy |------------------------------------- 3 ------| 1- 2 ------ 4 -----------------------------| very difficult
Pilot B very easy |-- 3 ---- -------------------------------2 ----|--------- 1-------------------------- 4 -----| very difficult
Pilot C very easy |------ 2 ------------------------------ 3 - 1 -|-- 4 ----| very difficult

Ability to establish / maintain comfortable sink rate:

Pilot A very easy |------------2-3-----------------------------|------------1--------4---------------------| very difficult
Pilot B very easy |-- 3 -- 2 -----------------------------------|---------------- 1------------------- 4 -----| very difficult
Pilot C very easy |---- 2 3 ------------------------------------|------------------- 1 --------------- 4 -----| very difficult

Linearity of response to control relationship:

linear

Pilot A small to large |--- 4 -------- 1 ------------------ 2 – 3 ---|---| large to small
Pilot B small to large |-- 4 1------------------------------------ 3 ----------- 2 -----------------------------| large to small
Pilot C small to large |-------------------- 4 1 -------------------3 2 --| large to small

Sensitivity to pilot bandwith:

Pilot A insensitive |---------------------------------- 3 ------|------ 2 – 1 ------------------- 4 ---------| extremely sensitive
Pilot B insensitive |--- 3-- 2------------ 1 ------------ 4 ---------| extremely sensitive
Pilot C insensitive |---------- 2 3 --------- 1 ------------------|-------------- 4 -------------------------| extremely sensitive

Necessity to open loop to perform task:

Pilot A not required |----- 4 ------ 1 ------------------------- 2 -|----- 3 --| essential for success
Pilot B not required |------ 1234 -----------------------------------|--| essential for success
Pilot C not required |--- 1------------------------- 2 3 ----------|-------- 4 --------------------------------------| essential for success

Overall precision of control:

Linear

Pilot A perfect |--- 2 3--|------------- 1 ------ 4 ------------------| grossly unsatisfactory
Pilot B perfect |--------------- 3 -----------------------------|---------- 2 ---------- 1--------- 4 --------| grossly unsatisfactory
Pilot C perfect |--------------- 3 ----- 2 --------------------|--------------- 1---------------------- 4 --| grossly unsatisfactory

Perception of control stick dynamics:

Pilot A very comfortable |--------------------------------2-3-1-4-------|---------------------- ---------------------| very annoying
Pilot B very comfortable |-------- 3-2-1-4------------------------------|-------------- ----------------------------| very annoying
Pilot C very comfortable |-3412---|---| very annoying

APPENDIX J – VVSLIS DESCRIPTION

Veridian Variable Stability Learjet 24 In-flight Simulator (VVSLIS): The VVSLIS aircraft (tail # N101VS) was a modified Learjet model 24D that served as a three axis in-flight simulator through implementation of a Variable Stability System (VSS). The safety pilot's controls (left seat) were standard Learjet controls, but the evaluation pilot's controls (right seat) were replaced with components of fly-by-wire, response feedback, variable stability, and variable control systems. The evaluation pilot's controls consisted of a centerstick for pitch and roll control, and foot pedals for yaw control. The response feedback flight control system used the Learjet control surfaces to augment the stability characteristics of the basic Learjet. The VVSLIS aircraft included the following capabilities:

1) Variable feel system with centerstick and sidestick controllers
2) Aircraft motion sensors and associated signal conditioning
3) Control system simulation computer
4) Control surface servos
5) Digital configuration control system
6) Engage/disengage and safety monitoring logic
7) Data recording and playback capabilities.

Variable Stability System (VSS): The VSS is divided into two independent parts: The first part, the variable feel system, provided the evaluation pilot with the stick and rudder pedal forces, gradients, and displacements. The second part, the response feedback flight control system, augmented the normal Learjet dynamics to represent those of the vehicle being evaluated. The evaluation pilot's inputs were fed into the flight control system through the feel system, and the resulting control surface movements produced an aircraft response. The control loop was closed by sensing the aircraft's motions and feeding back signals proportional to those motions. These feedback signals were combined with the evaluation pilot's command signals to create the in-flight simulation. Angle of attack vanes, sideslip vane accelerometers, rate and attitude gyros, and air data information were used as the sensor elements. The VSS flight control modes were as follows:

VSS MODE: For purposes of HAVE WRIGHT, this mode was the in-flight simulation of the 2003 Wright flyer. The Veridian simulation engineer could make in-flight changes to this mode to simulate four possible configurations of the 2003 Wright Flyer. These configurations were:

1) 2003 Wright Flyer – Pitch SAS off, Roll SAS off, WRI on
2) 2003 Wright Flyer – Pitch SAS on, Roll SAS off, WRI on
3) 2003 Wright Flyer – Pitch SAS on, Roll SAS on, WRI on
4) 2003 Wright Flyer – Pitch SAS off, Roll SAS off, WRI off

APPENDIX J – VVSLIS DESCRIPTION (CONT'D)

WRI – Warp Rudder Interconnect – a mechanical connection from wing warp to rudder that reduced adverse yaw. This was simulated with software interconnection of the ailerons and rudder onboard the VVSLIS aircraft.

SAS – Stability Augmentation System – a rate feedback system that augmented stability

EMERGENCY FLY BY WIRE (FBW) MODE: In the event the safety pilot became incapacitated or certain control cable failures occurred, the evaluation pilot could fly the aircraft as a normal Learjet using the FBW mode. In this mode, all basic Learjet systems (gear, flaps, spoilers, brakes, etc.) were available. The handling characteristics were those of the basic Learjet 24 aircraft with the yaw damper on. All VSS safety trips were disabled and no feedback loops were used except rudder deflection per sideslip rate for yaw damping.

EVALUATION PILOT MANUAL DISENGAGE MODE: The evaluation pilot could electrically disengage the VSS and return control of the aircraft to the safety pilot. A disengage switch was located on the right seat center stick.

SAFETY PILOT MANUAL DISENGAGE MODE: The safety pilot may disengage the VSS by depressing any of the following: wheel master switch, glare shield disengage switch, or throttle quadrant disengage switch.

FORCE DISENGAGE MODE: A large force input by the safety pilot to the normal Learjet wheel/column would cause the VSS to disengage. Additionally, if any of the following parameters were exceeded, the system would disengage with control given to the safety pilot:

Maximum Angle of Attack:	+10 deg/-5 deg
Aileron Surface Rate:	200 deg/sec
Maximum Angle of Sideslip:	15 deg
Lateral Acceleration:	+0.3 g
Normal Acceleration:	+2.8 g/+0.15 g
Elevator Surface Rate:	100 deg/sec
Hinge Moments:	Elevator: 680 psi
	Aileron: 550 psi
	Rudder: 660 psi

APPENDIX J – VVSLIS DESCRIPTION (CONT'D)

Note: When the VSS disengaged (manually or automatically), a yellow light would flash on the engage panel and a "beep, beep, beep…" would be heard on the interphone and cabin speakers.

VVSLIS SYSTEM MATURITY: The VSSLIS aircraft has been flown in hundreds of sorties including operational support test missions, USAF and Navy Test Pilot School curriculum sorties, and in-flight simulation of numerous aircraft configurations and flight control programs. A wide variety of stable and unstable aircraft have been simulated with the VVSLIS. VVSLIS evaluations have included offset and straight-in landings with various degrees of turbulence and crosswinds; formation and air-to-air tracking tasks, aerodynamic sensitivity evaluations including both longitudinal and lateral-directional variations, and flight control variations including gain changes, command variable changes, and stick characteristic variations.

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APPENDIX K – SOFTWARE VERIFICATION

VERIDIAN ENGINEERING'S SOFTWARE VERIFICATION OF 2003 WRIGHT FLYER

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VERIDIAN
Flight Research Group

Document No: **TM-FLTR-LJ1-0069-R00**

Simulation Verification for the In-Flight Simulation of the Wright Flyer Aircraft With the Veridian Variable-Stability Learjet 24

May 2001

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Purpose

The purpose of this report is to document the verification of the simulation of the Wright Flyer airplane using the Veridian Variable-Stability Learjet 24 for the USAF Test Pilot School (AFTPS) HAVE WRIGHT Test Management Project (TMP).

Verification Methods

Feel System

Feel system static properties were measured by performing slow control sweeps in all three axes and recording control forces and positions. The results were compared to the design values.

All feel system characteristics were measured on the ground with the hydraulic system fully powered in the Ground Simulation mode. The variable-feel system operates in exactly the same manner in flight as on the ground.

Flight Control System

The gains and architecture of the stability augmentation systems (SAS) were implemented as defined by the AIAA and confirmed by the AFTPS, and step response check cases were provided to Veridian. The Veridian offline model outputs were compared with the output canard and wing warp deflections of the control system the AIAA supplied check cases in each axis. The Simulink implementation of the Wright Flyer flight control system was also reviewed by AFTPS project engineers.

Aerodynamic Model

The Wright Flyer aerodynamic model delivered to Veridian was in linear state-space form in the body-axis system. Additionally, the AIAA provided aerodynamic derivatives and transfer functions that confirmed the model characteristics. Changes to the original state-space model were provided in terms of non-dimensional derivatives, and then Veridian recalculated the resulting state-space model. The VSS real-time implementation of the aerodynamic model was a six degree-of-freedom Simulink model with linear aerodynamics and nonlinear kinematics. Model-following control laws were used to control the VSS Learjet to follow the model in pitch, roll and yaw. Accordingly, the aerodynamic model simulation verification was performed in two steps:

1. Verify the implementation of the Wright Flyer linear model in Simulink (comparing the Veridian offline model with the AIAA state space model).
2. Verify the accuracy with which the VSS Learjet follows the Simulink model (comparing the VSS onboard implemented model with the recorded Learjet response).

Simulink Implementation of State-Space Model

The Simulink aerodynamic model implementation was validated by running it in parallel with a simple Simulink "State-Space" block and comparing the results. Additionally, the offline model results were plotted next to check cases provided by Systems Technology Inc. (STI) on behalf of the AIAA.

VSS Learjet Model-Following Accuracy

VSS Learjet model-following accuracy was measured by performing test inputs in flight and over-plotting VSS model and Learjet responses in real time. Model body-axis rates were rotated from the stability-axis to the Learjet body-axis in order to make a valid comparison.

Frequency Domain Model Verification

Frequency sweeps were performed during the calibration flights to compare open-loop aerodynamics of the VSS Learjet implementation with the Veridian offline model and the AIAA state space model. The transfer functions

used for aerodynamic model comparison were those relating the pitch or roll rate to the Wright Flyer canard or wing warp deflection for the respective pitch and roll axes. Additionally, closed-loop transfer functions were computed using pitch or roll stick deflection as the input to compare SAS-on cases that included the effects of the flight control system. The frequency sweeps performed on the calibration flights were analyzed using a Fast Fourier Transform (FFT) to produce frequency response plots using the Learjet outputs and the VSS recorded model outputs. Offline model frequency responses were obtained by driving the offline model with an appropriately sized representative chirp input and performing an FFT. The AIAA state space model was used to provide a direct Bode frequency response for the appropriate transfer function using the Matlab "bode" command.

For direct comparison with the Learjet frequency response data, an effective phase delay was added to the offline model and state space model phase plots. This delay is the frequency domain representation of the model-following time delay of 45 milliseconds, which is the computation and implementation time delay required to perform the model-following simulation on the Learjet. The effective phase angle is based on the formula for phase angle increase due to a pure time delay where ω is the input frequency:

$$\Delta\text{phase} = \omega * \text{time delay} * (180 / \pi)$$

Results

The results from Veridian's calibration and validation flights indicated that the Variable Stability Learjet simulation matched the desired Wright Flyer flight characteristics. The highly unstable pitch characteristics combined with a large speed mismatch presented a considerable challenge in matching the pitch, roll, and yaw rate responses to pilot inputs. The results in the following sections show the simulation implemented on the Veridian Variable Stability Learjet provided excellent matching with the AIAA-provided math model response. Veridian's model-following techniques were successful in providing an accurate representation of the AIAA 2003 Wright Flyer to assess the handling qualities of the aircraft for the AFTPS HAVE WRIGHT TMP.

The data from the following sections were collected during the third calibration flight, conducted on 17 April, 2001, at Edwards Air Force Base, California. The first two calibration flights for the Wright Flyer program were conducted by Veridian in Buffalo, NY.

Feel System

Measured feel system static and dynamic characteristics are presented in Figures 1 through 3 as listed in Table I. Feel system plots show that the targeted force gradients were attained for each of the axes. Pitch axis force gradient was 6 pounds per inch (lb/in), roll force gradient was 2.8 lb/in, and the pedal force gradient was 30 lb/in.

Table I
Feel System Verification Plots

Figure	Description of Plot
1	Pitch Stick Force vs. Pitch Stick Position
2	Roll Stick Force vs. Roll Stick Position
3	Pedal Force vs. Pedal Position

Flight Control System

The flight control system (FCS) used on HAVE WRIGHT is shown in Figure 4. Validation of the FCS, specifically the SAS, is included in the plots shown in Figures 5 and 6. These plots include the output canard, warp, and rudder deflections from a step input, comparing the Veridian offline model with the AIAA supplied check case data. Flight control system effects are also included in plots from the Aerodynamic Model Verification portion of this document. The frequency domain plots in a later section also include the FCS for some transfer functions analyzed.

Aerodynamic Model

Simulink Implementation of State-Space Model

Comparisons of the Wright Flyer linear aerodynamic model (with nonlinear kinematics) and the state space linear model are presented in Figures 7 through 9 as listed in Table III. The Veridian offline model with *linear* kinematics and the AIAA state-space model matched exactly so these comparisons were not shown. However, due to the existence of instability in the baseline aerodynamics, and the use of rate feedback in the SAS, the effect of including *nonlinear* kinematics is noticeable in the long-term response in Figures 7 and 8. The plots also show that the SAS responds using the offline nonlinear dynamics, while the state-space response slowly diverges from the nonlinear response.

Open-loop unstable pitch response is shown in Figure 9 for several different model values. This plot shows the effects of the changes that were made to the pitch model characteristics during the program through comparisons of time-to-double. The 1903 model time-to-double was predicted to be 0.35 seconds. Early in the program Mr. Henry Jex indicated that the airfoil on the 2003 replica would be altered and the cg would be shifted which resulted in a change in the $C_{M\alpha}$ when compared with the original AIAA information, but the aircraft is still unstable, and had a predicted time-to-double of 0.45 seconds. Based on the quickness of the unstable response, it was decided jointly by Veridian, the AIAA, and the TMP test team to improve the pitch damping of the model by doubling the value of C_{Mq}. This resulted in open-loop time-to-double amplitude of about 0.8 seconds. Veridian had previously demonstrated landings on our in-flight simulators with aircraft models with this type of response, while 0.4 seconds was considered un-flyable. The improved C_{Mq} value was felt to be more representative according to some subsequent tail volume analysis performed by Dr. Culick. Also in Figure 9 is an overlay plot showing the resulting Learjet impulse response from the calibration flight, validating that the open-loop aircraft flown in the evaluation flights demonstrated 0.8 seconds time-to-double.

Table II
Aerodynamic Model Validation Plots

Figure	Description of Plot
7	Pitch Stick Step – Offline Model with Nonlinear Kinematics, SAS on
8	Roll Stick Step – Offline Model with Nonlinear Kinematics, SAS on
9	Rudder Doublets – Offline Model with Nonlinear Kinematics, SAS off
10	Open-loop Unstable Pitch Response – Model Comparisons

Further Aerodynamic Model Validation is shown in the plots of the following sections. The Model-Following time history plots include comparisons of the offline model response with the VSS recorded model as well as Learjet response. The Frequency Domain plots also show these same comparisons in the frequency domain.

VSS Learjet Model-Following Accuracy

Representative plots comparing the Learjet pitch, roll, and yaw rate responses with those of the validated model are presented in Figures 10 through 13 as listed in Table III. These plots also include pitch, roll, and yaw rate responses for the offline model, illustrating the response differences incurred in implementing the model onto the VSS Learjet platform. These differences may be due to the large speed mismatch between the Wright Flyer and the Learjet and may also represent some of the limitations involved in using model-following with such an unconventional model on the 3-degree-of-freedom Learjet In-flight simulator. Because of the large velocity mismatch between the model and the Learjet, the steady-state yaw rate responses in steady turns are different due to the differences in kinematics. The short-term yaw rate response appears reasonably accurate.

Table III
Model-Following Verification Plots

Figure	Description of Plot
11	Pitch Stick Step Response – Pitch SAS On
12	Roll Stick Step Response – Roll SAS Off, WRI On
13	Roll Stick Step Response – Roll SAS On, WRI On
14	Roll Stick Step Response – Roll SAS Off, WRI Off
15	Rudder Doublet Response – Roll SAS Off, WRI Off

Frequency Domain Model Verification

Frequency Domain Model Verification plots are shown in Figures 16 through 21 as listed in Table IV. The frequency domain results were very good, showing good correlation with the time history results. The frequency sweeps performed on the calibration flights provided excellent data to analyze with FFT methods. The resulting transfer function frequency response data on all of the plots had coherence above 90%. In the range of frequencies up to 10 rad/sec, the Learjet frequency response matched well with the offline model and state space models. This frequency range is well within the pilot operating range, even for high gain tasks. At low frequencies for the pitch open-loop frequency response, the Learjet and VSS Model phase angles diverged from the offline model and state space model, possibly due to the unstable response of the aircraft, and the fact that the pilot was required to always input corrections to keep the aircraft from departing. Low frequency data is therefore very difficult to obtain with an unstable aircraft.

The model-following plots showed good model-following accuracy, with some high frequency differences due to the actuator dynamics of the Learjet. For the FCS and Aerodynamic frequency response data (transfer functions q/δ pitch stick and p/δ roll stick), the correlation between the offline model and the VSS model was excellent. These data were high quality and would be excellent candidates for applying various frequency domain handling qualities criteria for comparison with the evaluation pilots' ratings.

Table IV
Frequency Domain Model Verification Plots

Figure	Description of Plot
16	Pitch Model Validation Frequency Response Comparison – q / δ canard, Learjet Response vs. Offline Model
17	Pitch Model-Following Frequency Response Comparison – q / δ canard, Learjet Response vs. VSS Model
18a	Pitch FCS & Aero Frequency Response Comparison – q / δ pitch stick, VSS Model vs. Offline Model
18b	Pitch FCS & Aero Frequency Response Comparison – q / δ pitch stick, Learjet Response vs. Offline Model
19	Roll Model Validation Frequency Response Comparison – p / δ wing warp, Learjet Response vs. Offline Model
20	Roll Model-Following Frequency Response Comparison – p / δ wing warp, Learjet Response vs. VSS Model
21	Roll FCS & Aero Frequency Response Comparison – p / δ roll stick, VSS Model vs. Offline Model

Figure 1. Pitch Control Sweep

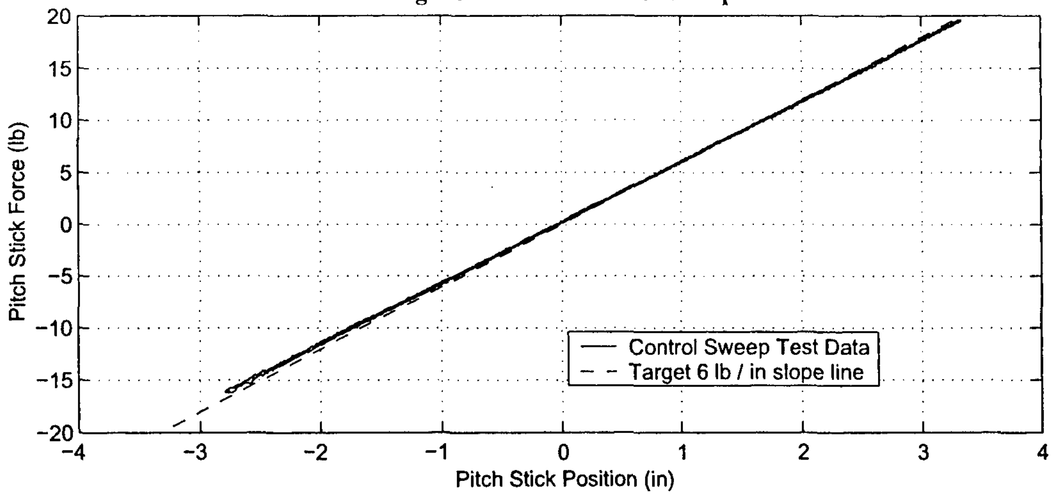


Figure 2. Roll Control Sweep

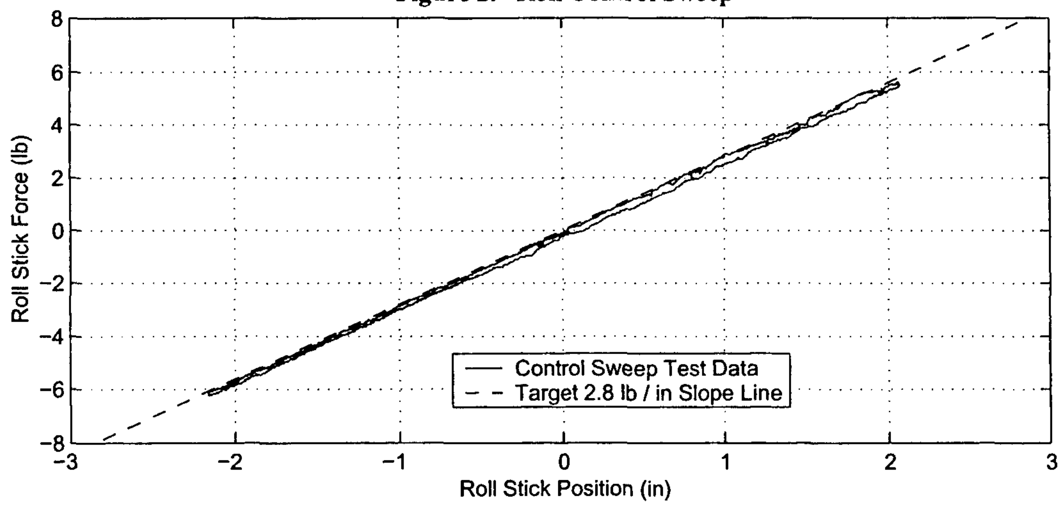


Figure 3. Rudder Pedal Sweep

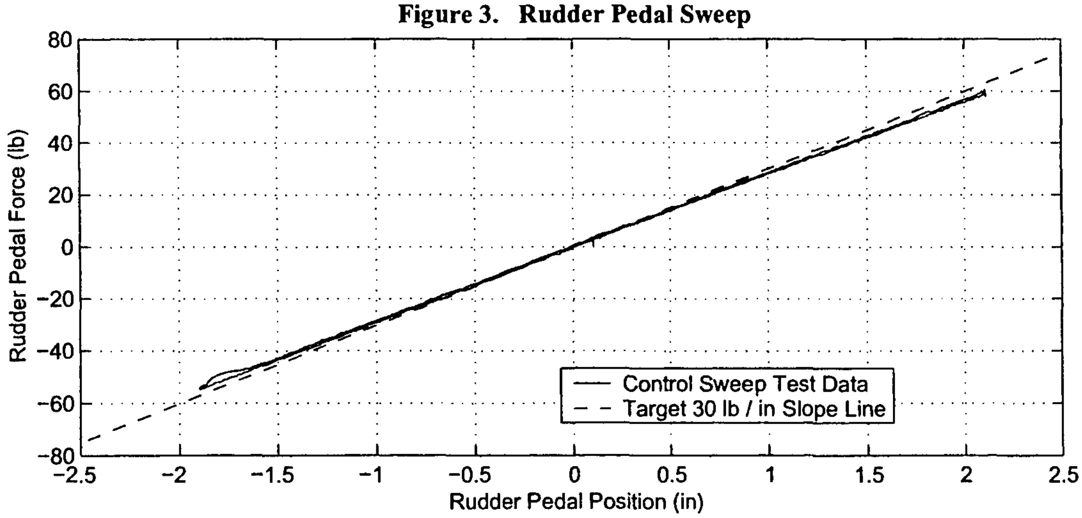
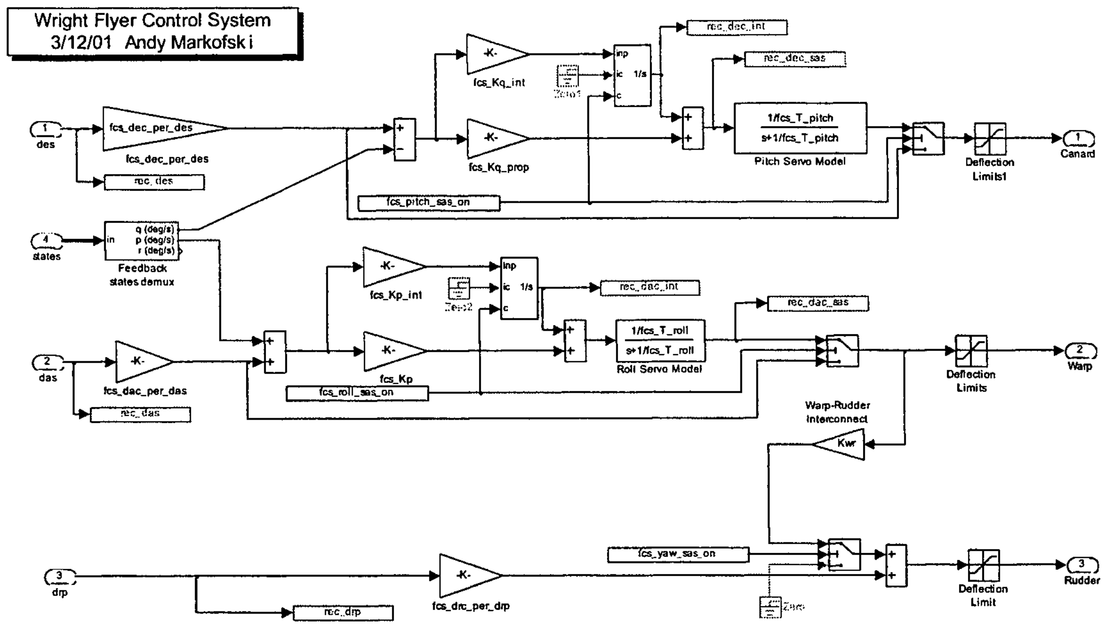


Figure 4. HAVE WRIGHT Flight Control System



FCS Diagram Name	Explanation	Value
fcs_dec_per_des	pitch command gain	2.0
fcs_Kq_prop	pitch proportional gain	0.4
fcs_Kq_int	pitch integrator gain	1.4 (3.5*0.4)
fcs_psas_int_llim	lower pitch integrator limit	-10.0
fcs_psas_int_ulim	upper pitch integrator limit	10.0
fcs_p_act_llim	lower pitch deflection limit	-10.0
fcs_p_act_ulim	upper pitch deflection limit	10.0
fcs_dac_per_das	roll command gain	-4.0
fcs_Kp_prop	roll proportional gain	1.0
fcs_Kp_int	roll integrator gain	3.0
fcs_rsas_int_llim	lower roll integrator limit	-20.0
fcs_rsas_int_ulim	upper roll integrator limit	20.0
fcs_r_act_llim	lower roll deflection limit	-20.0
fcs_r_act_ulim	upper roll deflection limit	20.0
fcs_drc_per_drp	pedal command gain	-6.0
Kwr	warp-rudder interconnect gain	1.25
model_dr_min	lower rudder deflection limit	-15.0
model_dr_max	upper rudder deflection limit	15.0
fcs_T_pitch	actuator time constant – pitch	0.025
fcs_T_roll	actuator time constant – roll	0.025

Figure 5a. Wright Flyer Pitch Comparison: Veridian Offline Model vs. STI Model, Pitch SAS On, Original Cmq Value

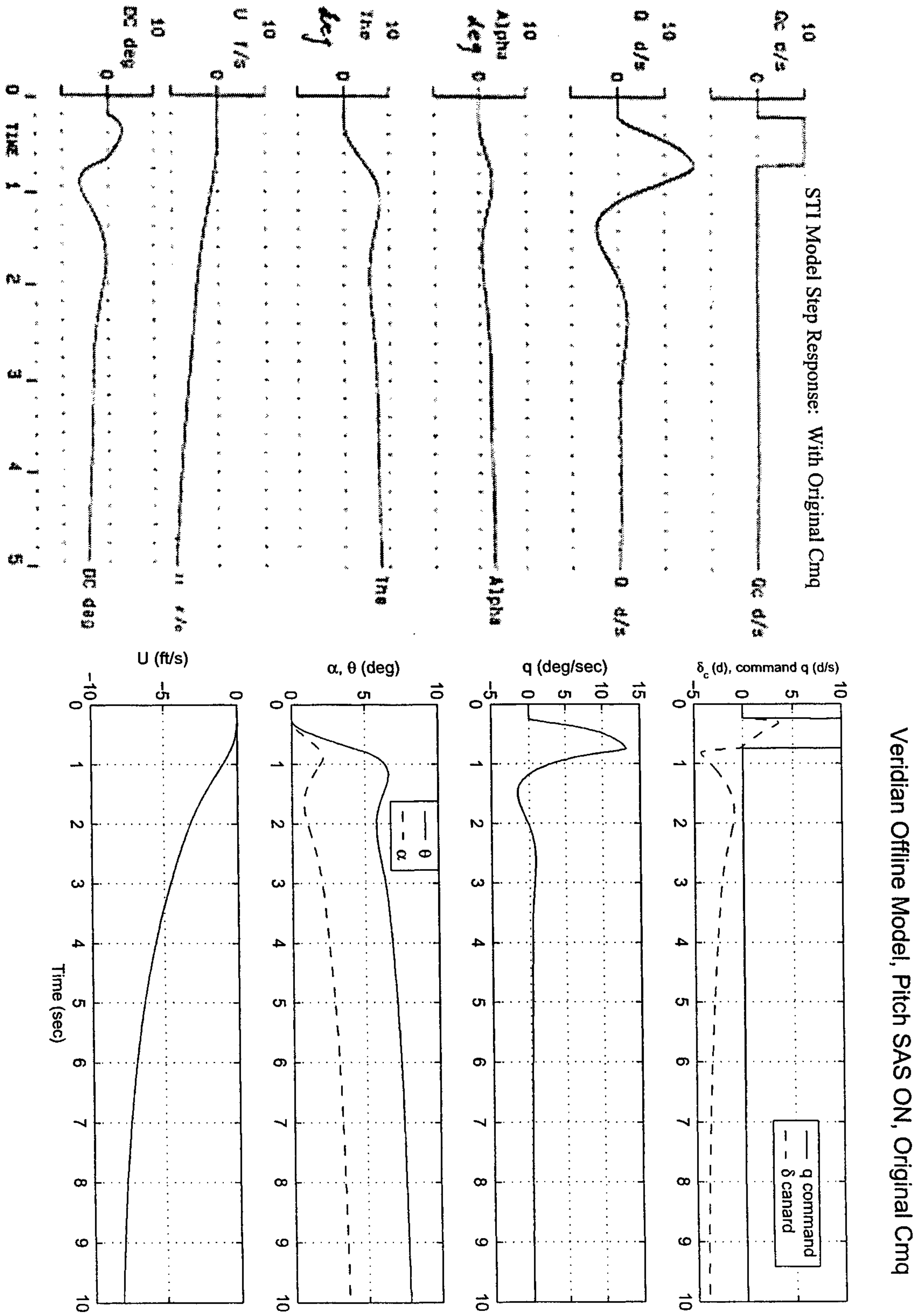
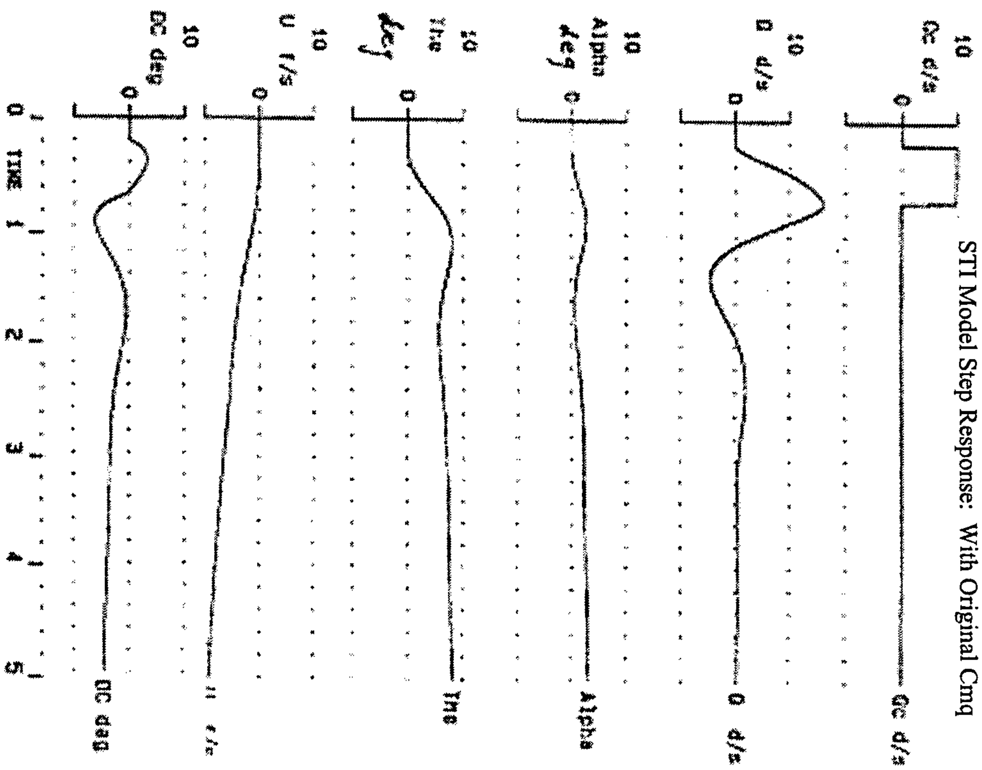


Figure 5b. Wright Flyer Pitch Comparison: Veridian Offline Model vs. STI Model, Pitch SAS On, Flight Test Cmq Value



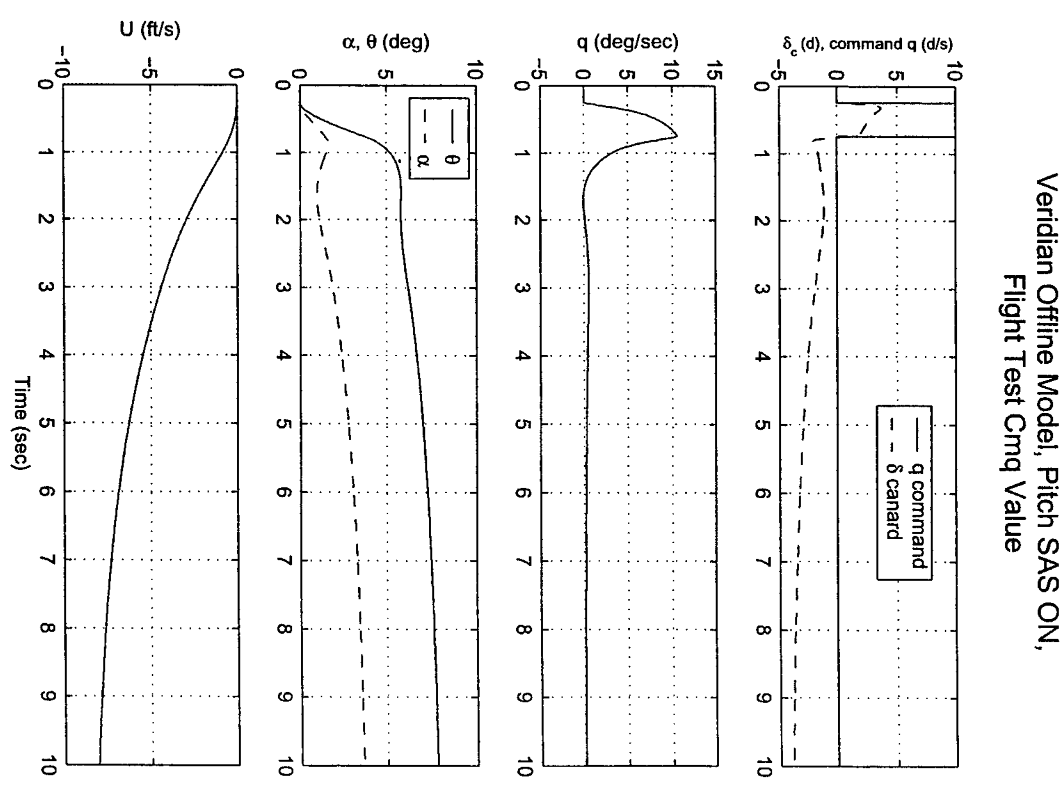


Figure 6a. Wright Flyer Model & FCS Comparison: Veridian Offline Model vs. STI Model, Roll SAS On (Part 1)

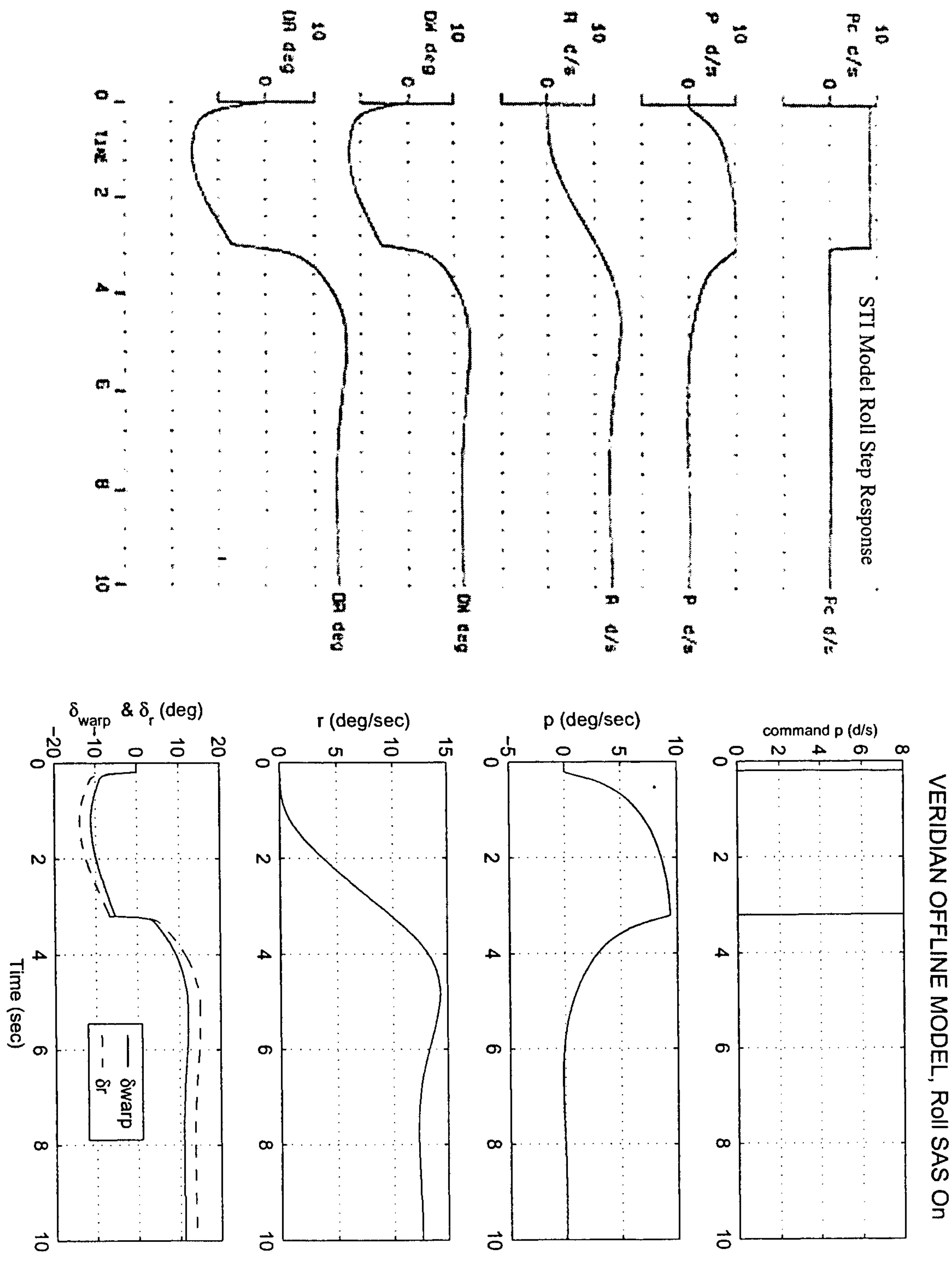


Figure 6b. Wright Flyer Model & FCS Comparison: Veridian Offline Model vs. STI Model, Roll SAS On (part 2)

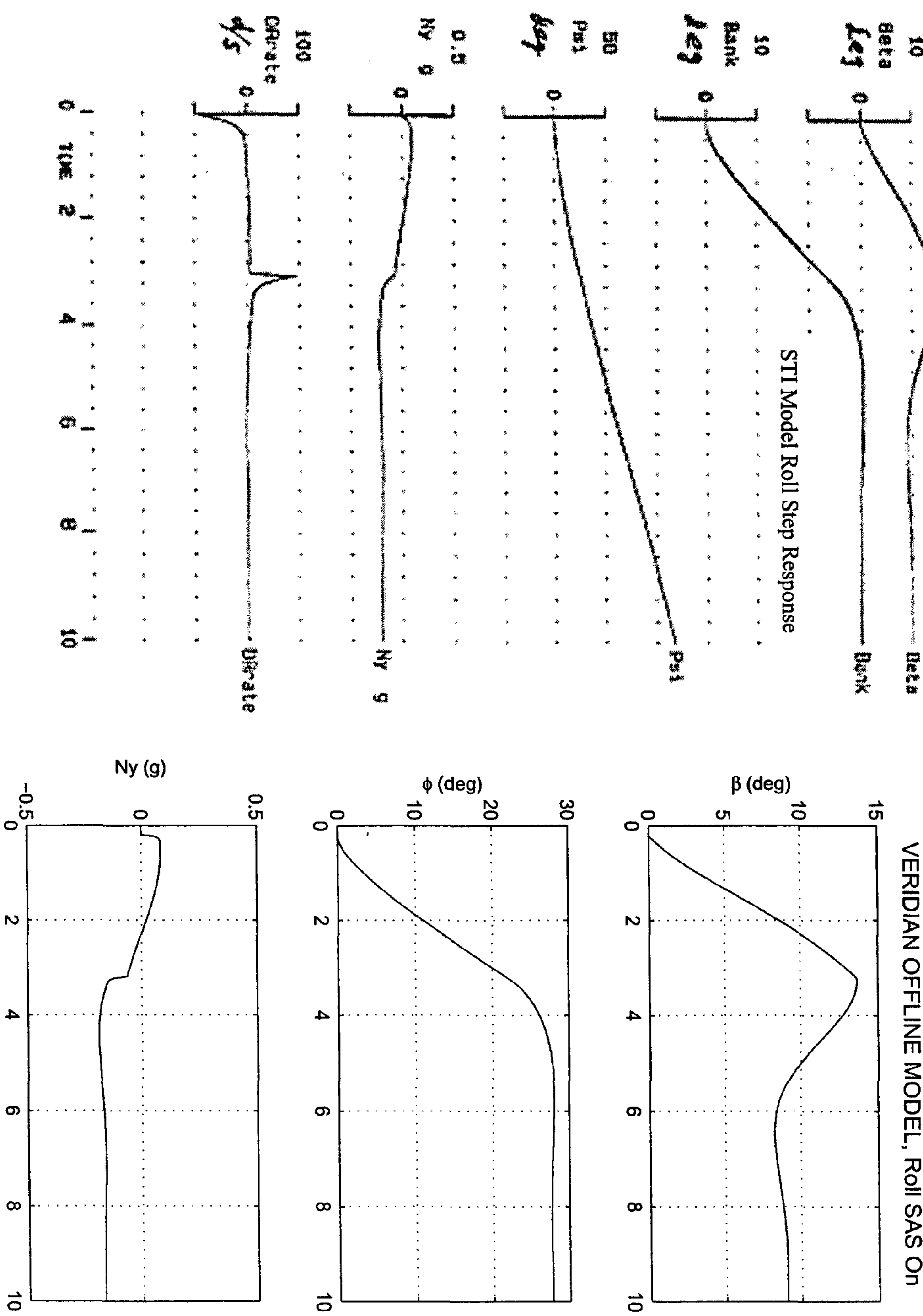


Figure 7. Comparison of State Space Model with Offline Nonlinear Model for Pitch SAS On Shows Effects of Nonlinear Kinematics for an Unstable Aerodynamic Model

Dashed Line Represents AIAA State Space Model and
Solid Line Represents the Offline Model with Nonlinear Kinematics

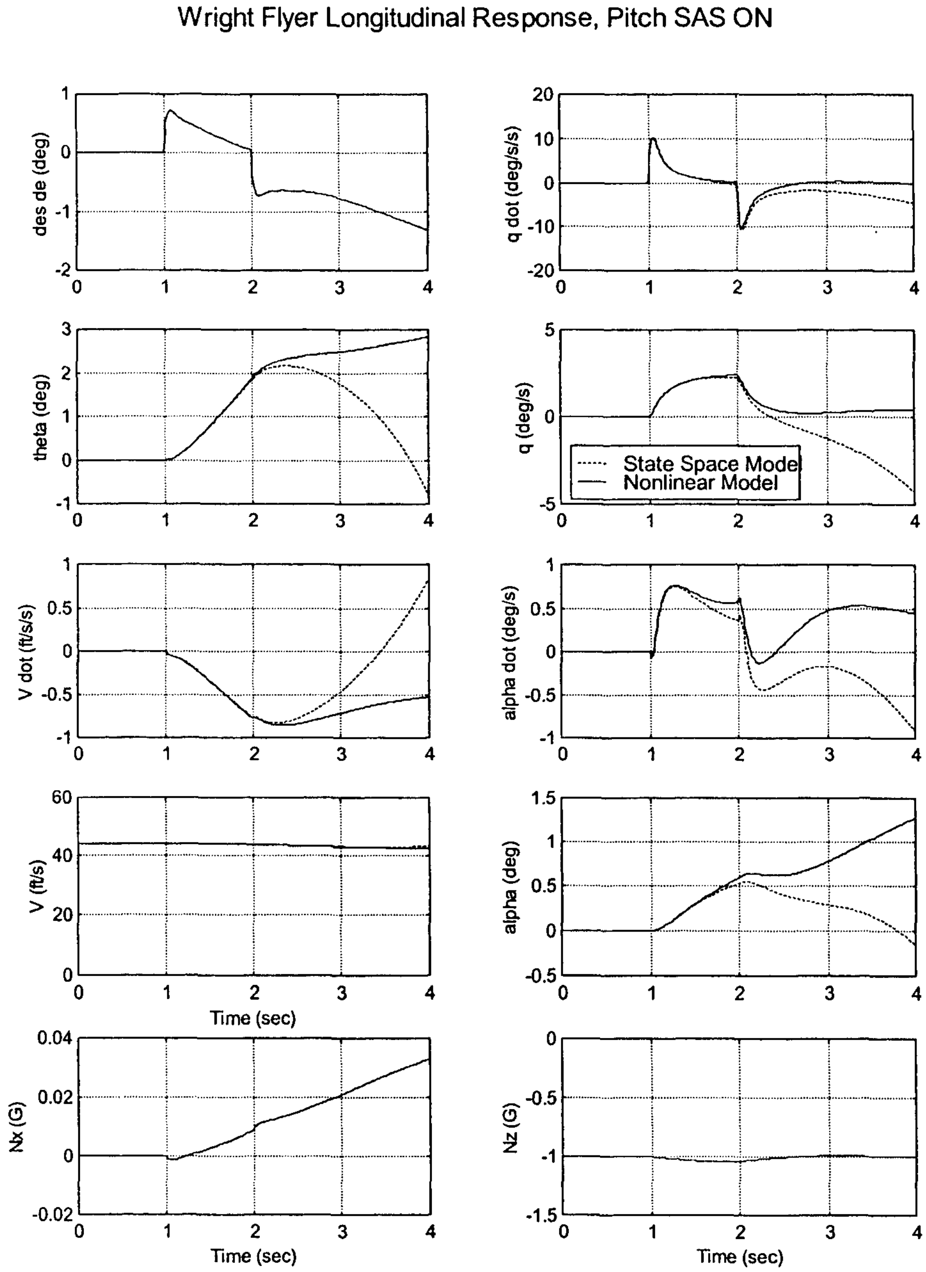


Figure 8. Comparison of State Space Model with Offline Nonlinear Model for Roll & Yaw SAS On Shows Effects of Nonlinear Kinematics for an Unstable Aerodynamic Model

Dashed Line Represents AIAA State Space Model and
Solid Line Represents the Offline Model with Nonlinear Kinematics

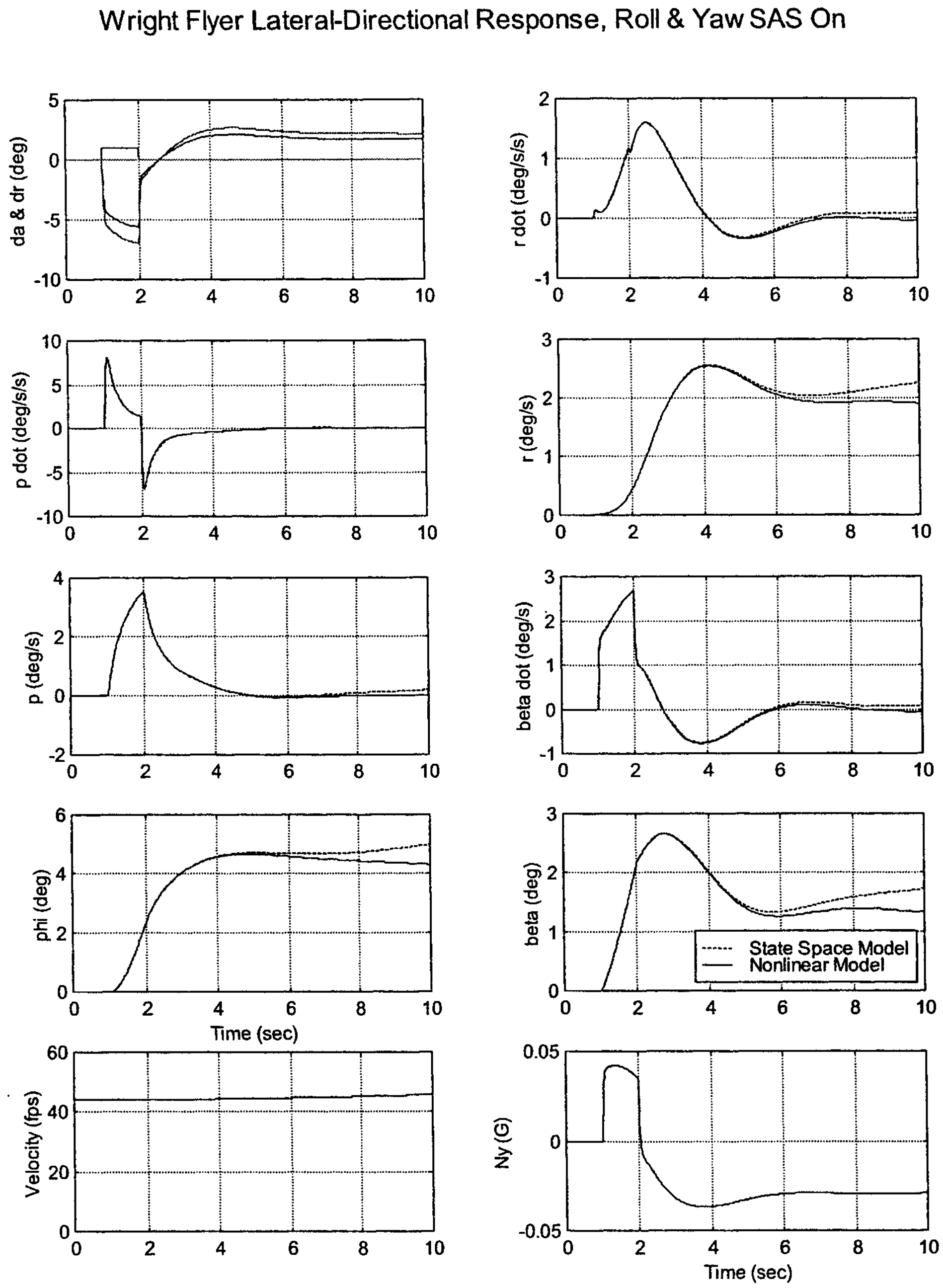


Figure 9. Comparison of State Space Model with Offline Nonlinear Model for Roll & Yaw SAS On Shows Effects of Nonlinear Kinematics for an Unstable Aerodynamic Model

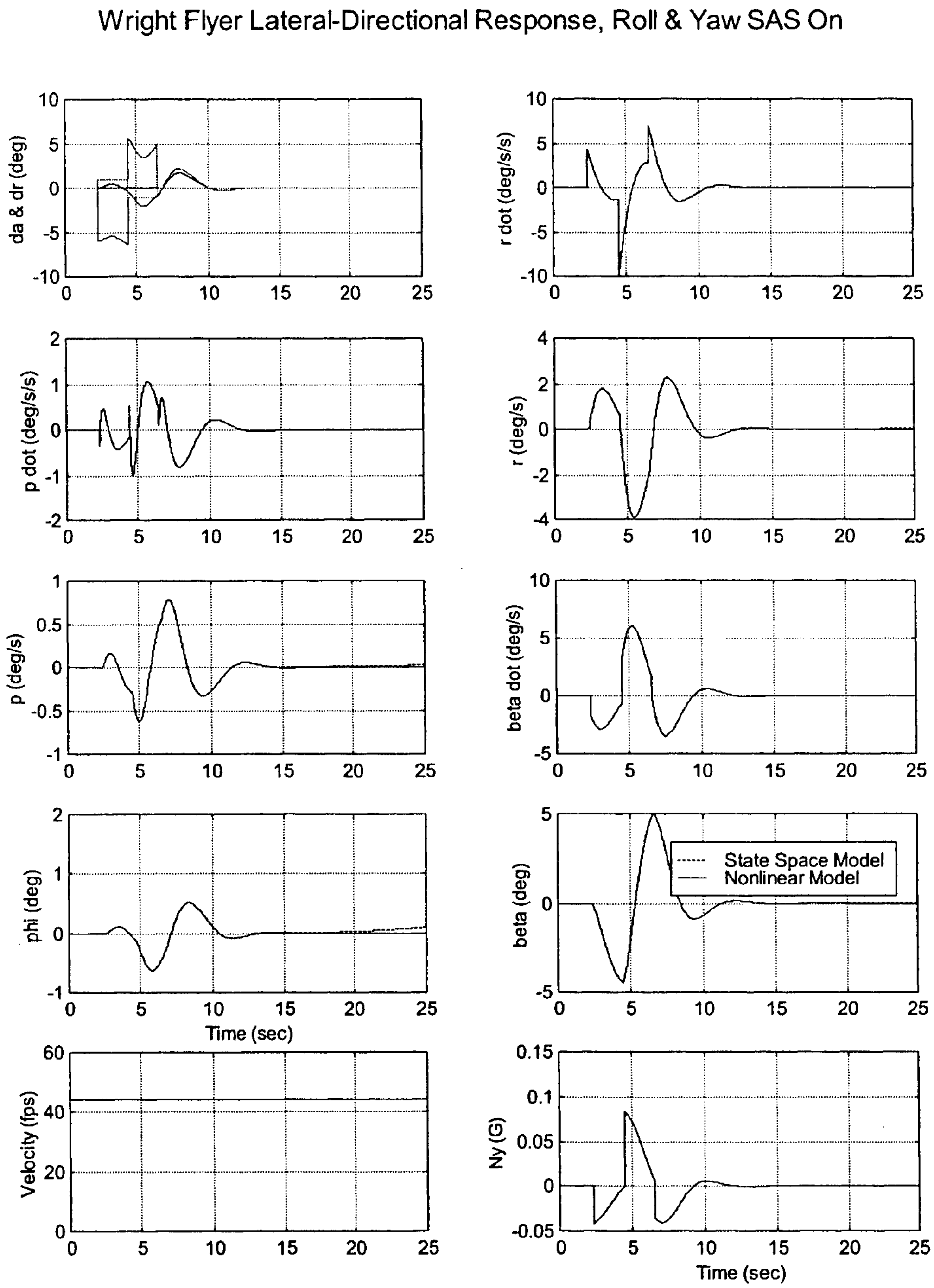


Figure 10. Pitch SAS Off, Open-loop Aerodynamic Model Validation, Impulse Response, Time-to-Double Amplitude Comparison

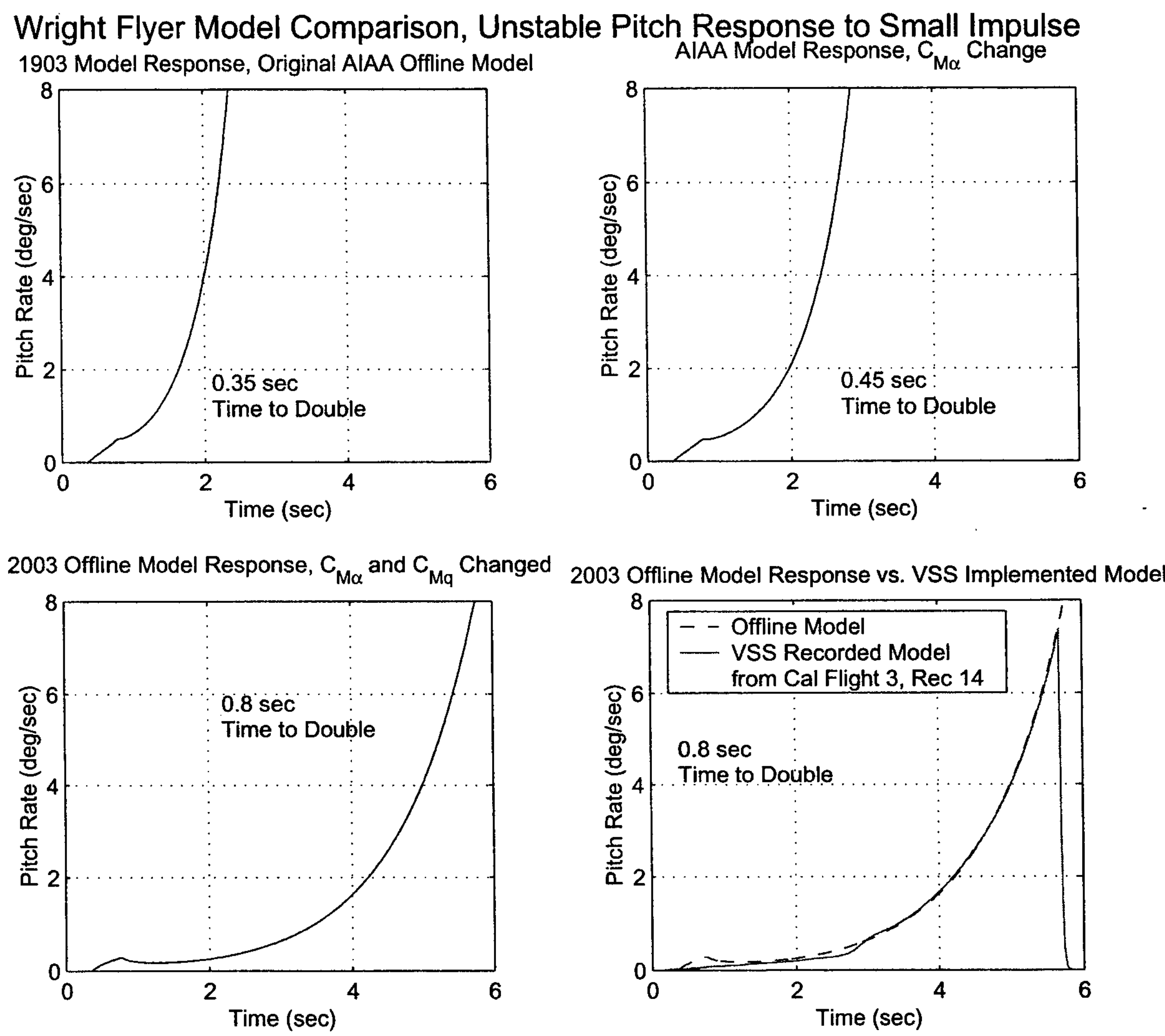


Figure 11. Model-Following and Model Validation for Pitch SAS On Step Response

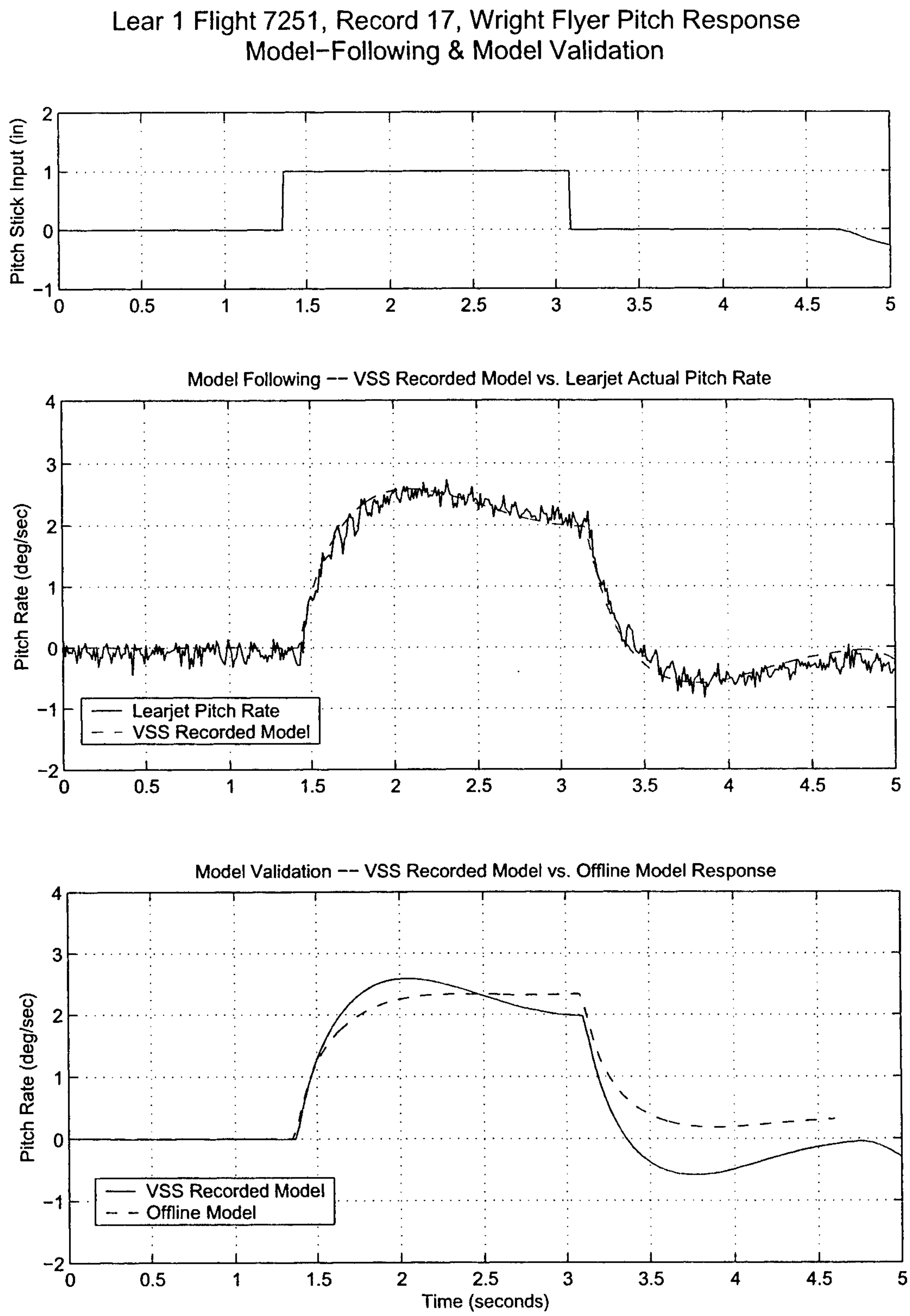


Figure 12. Open-loop Roll Step Response for Aerodynamic Model Validation and Model-Following Verification

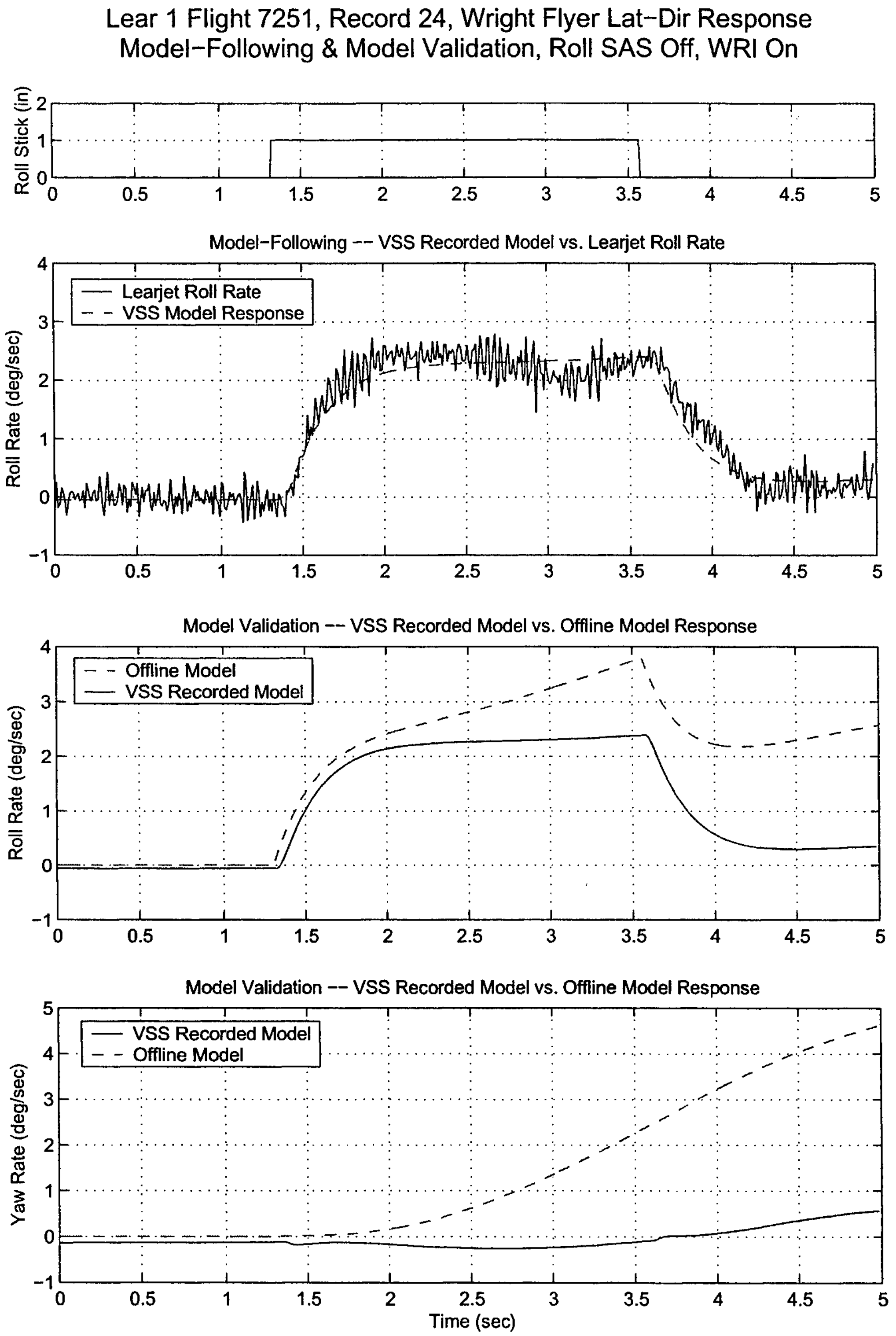


Figure 13. Model-Following and Model Validation for Roll SAS On Step Response

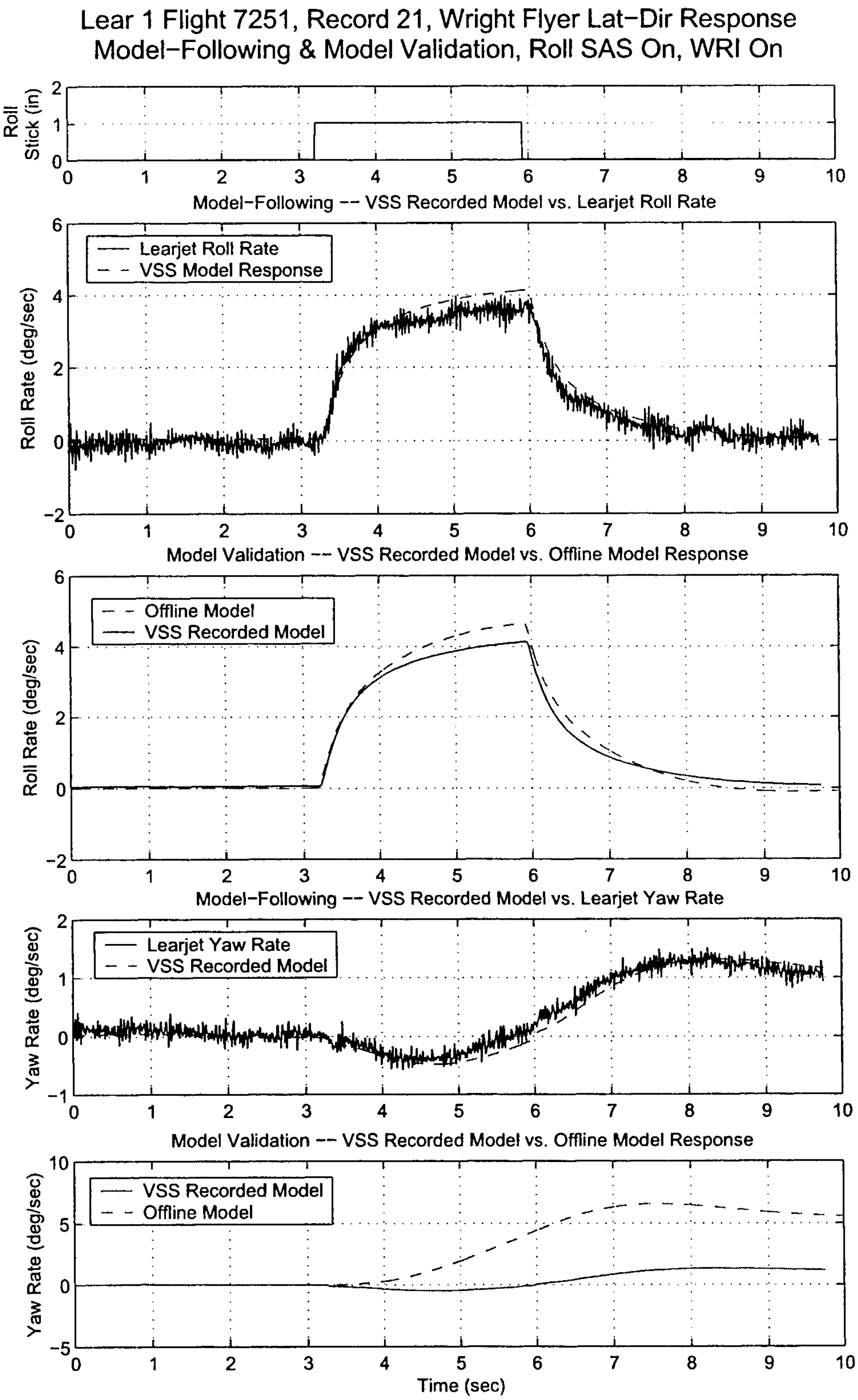


Figure 14. Aerodynamic Model Validation and Model-Following Verification WRI Off Open-loop Response to Step Input

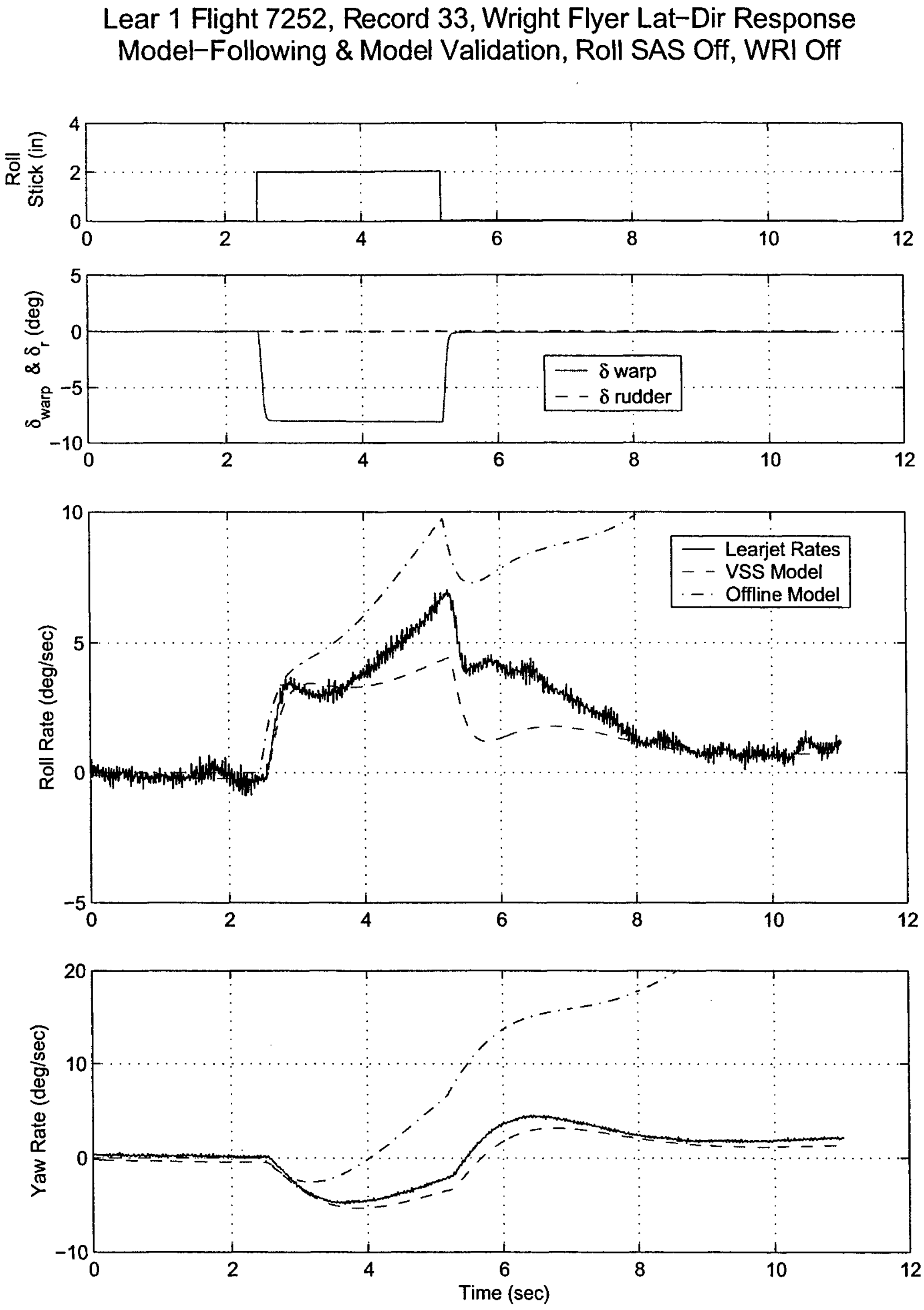


Figure 15. Aerodynamic Model Validation and Model-Following Verification
Roll SAS Off, WRI Off, Open-loop Response to Rudder Doublet Inputs

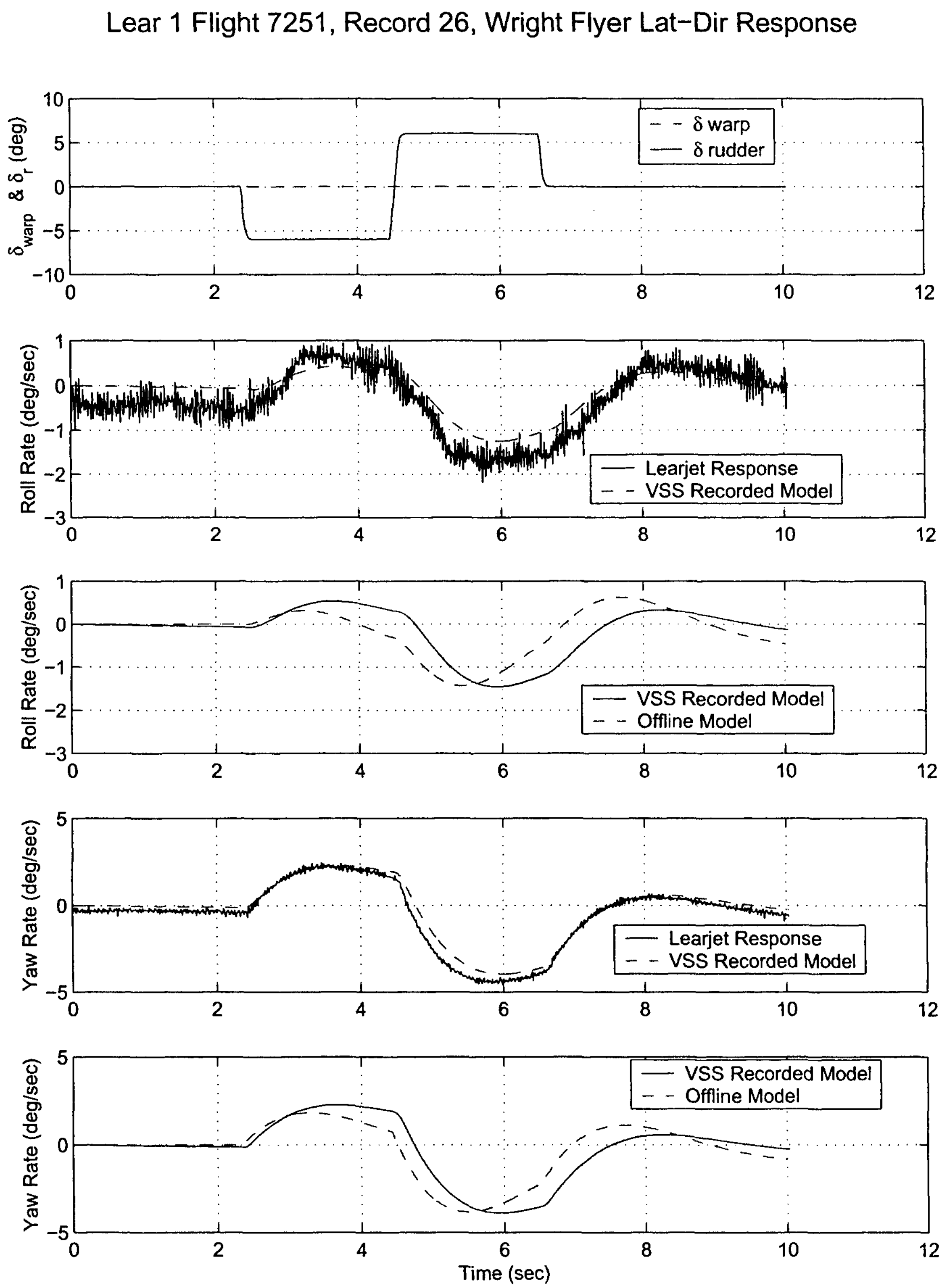
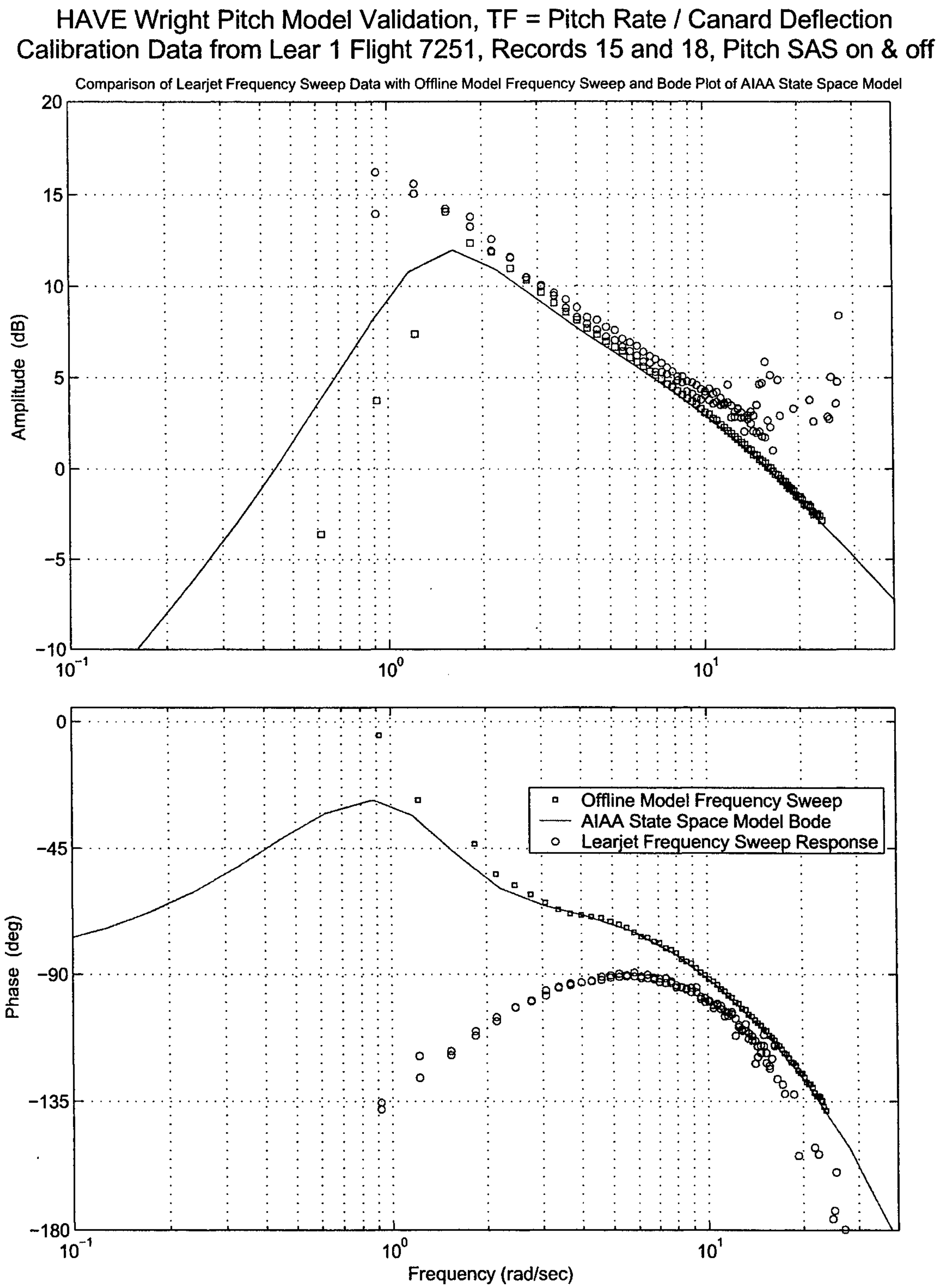


Figure 16. Frequency Domain Aerodynamic Model Validation – Pitch Axis State Space Model, Offline Model, and Learjet Frequency Response



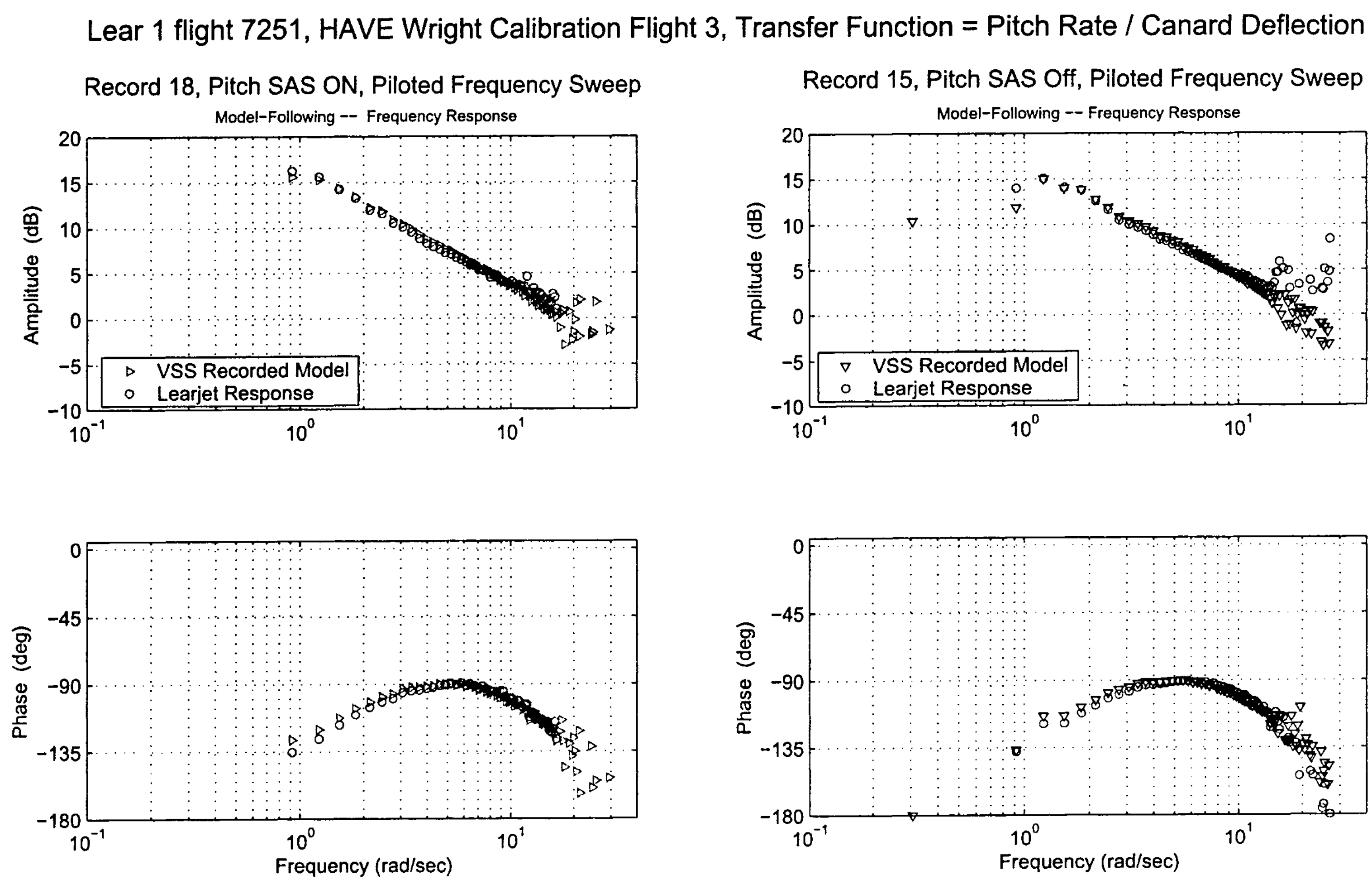


Figure 17. Frequency Domain Model–Following Verification – Pitch Axis

Figure 18a. Frequency Domain Aerodynamic Model and FCS Validation – Pitch SAS On VSS Recorded Model vs. Offline Model

Pitch SAS on, Wright Flyer, TF -- Pitch Rate / Pitch Stick Deflection

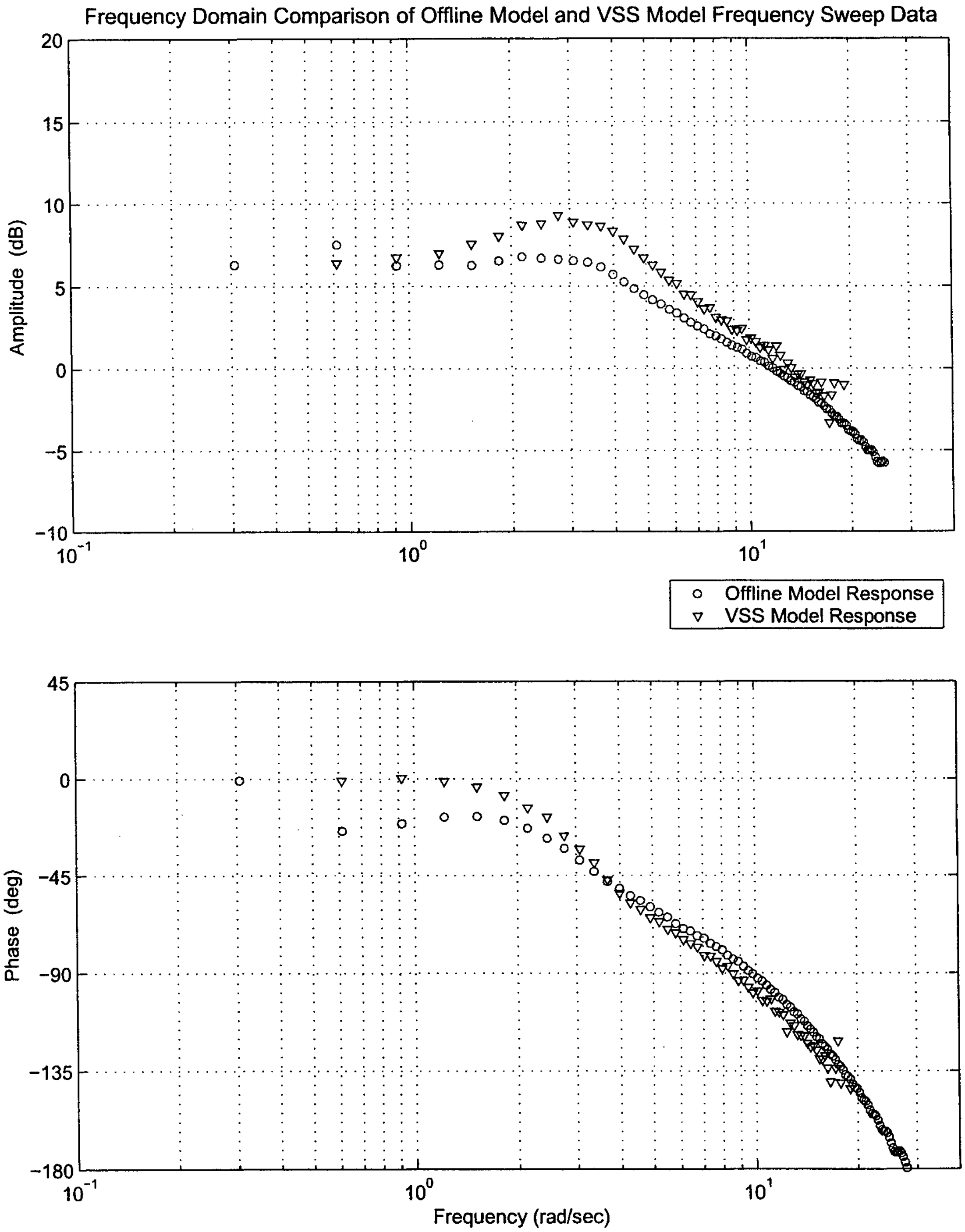


Figure 18b. Frequency Domain Aerodynamic Model and FCS Validation – Pitch SAS On Offline Model vs. Learjet Response

Pitch SAS on, Wright Flyer, TF -- Pitch Rate / Pitch Stick Deflection

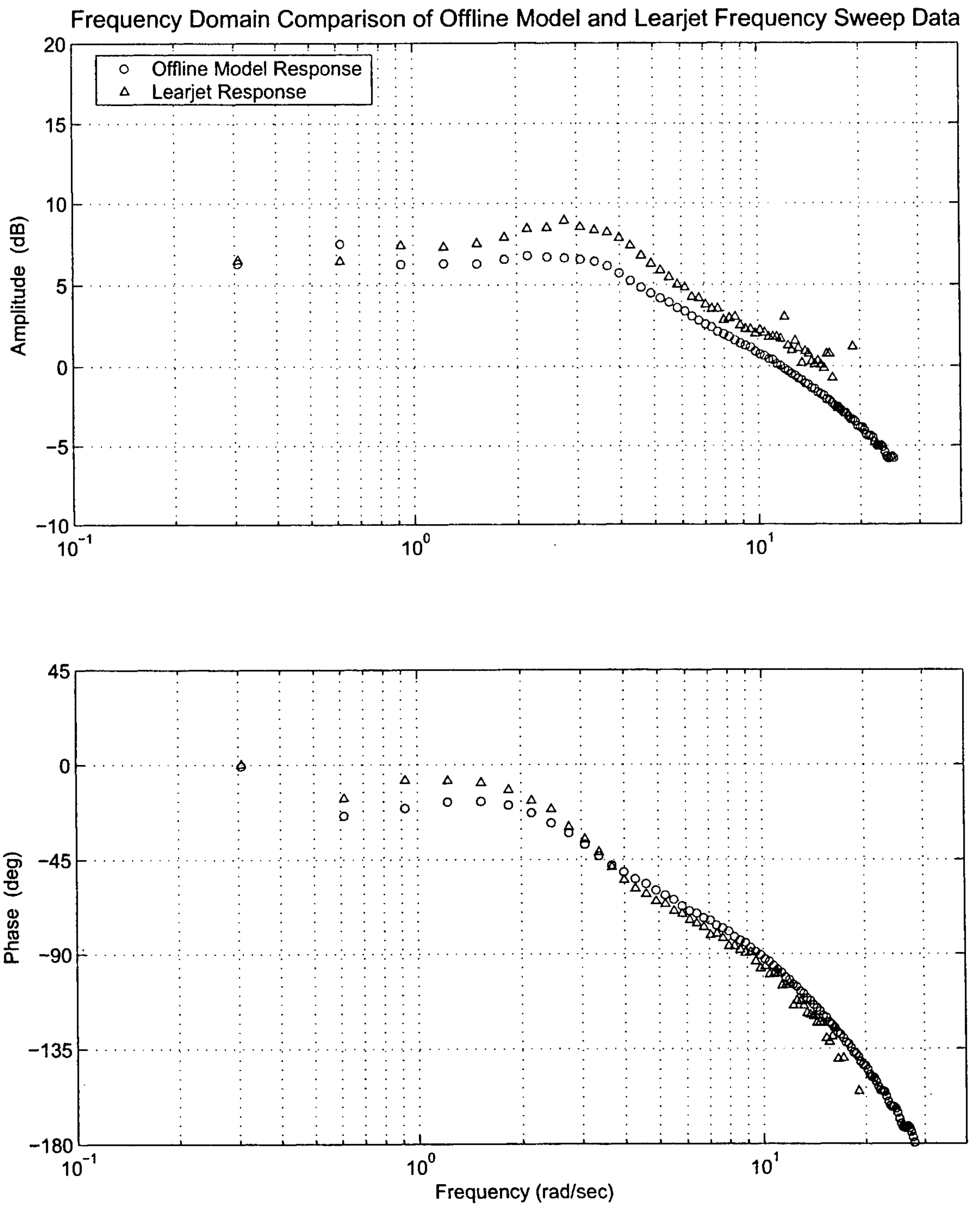
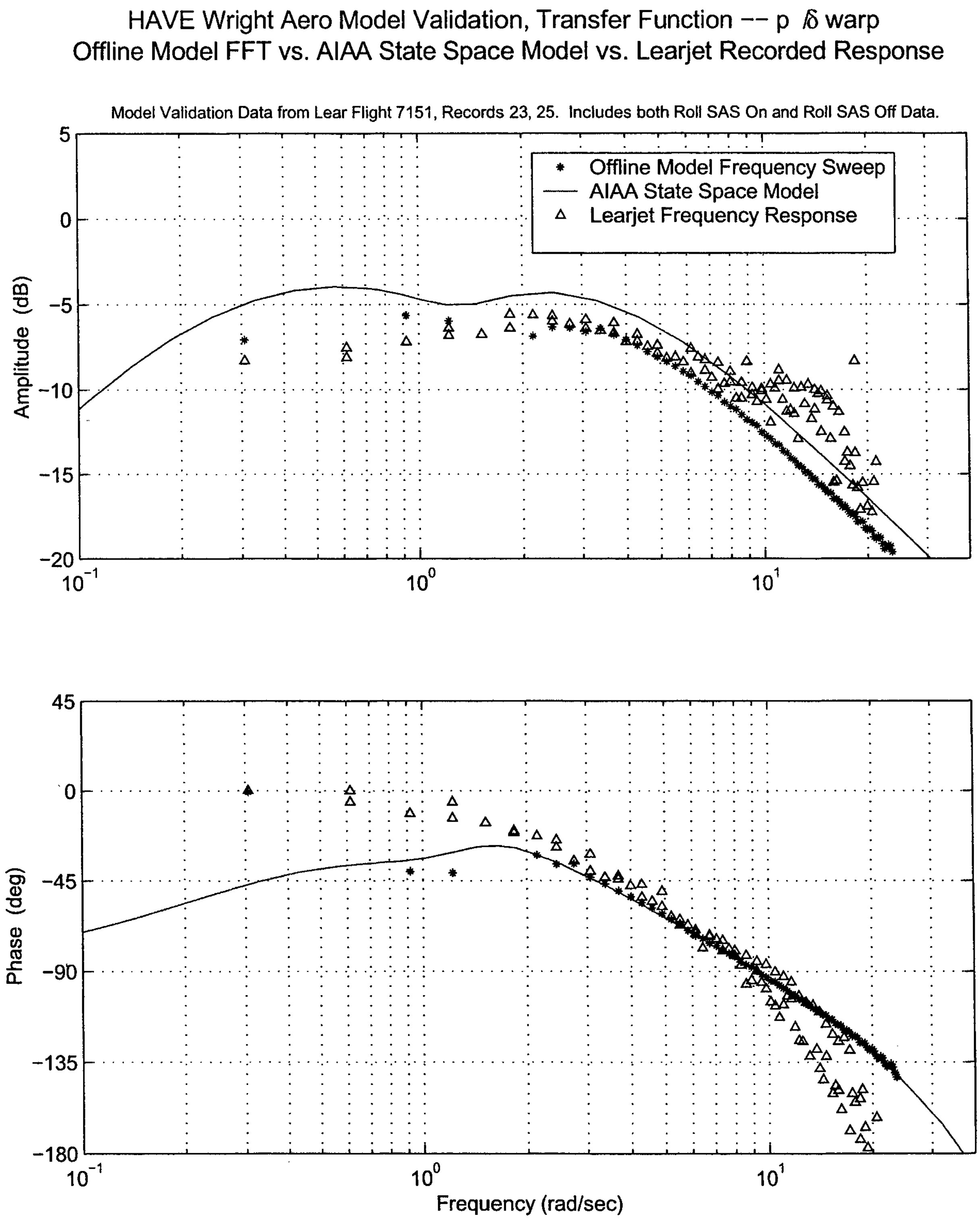


Figure 19. Frequency Domain Aerodynamic Model Validation – Roll Axis



HAVE Wright Roll Axis Frequency Sweep Model Following Comparison, TF p /δ warp

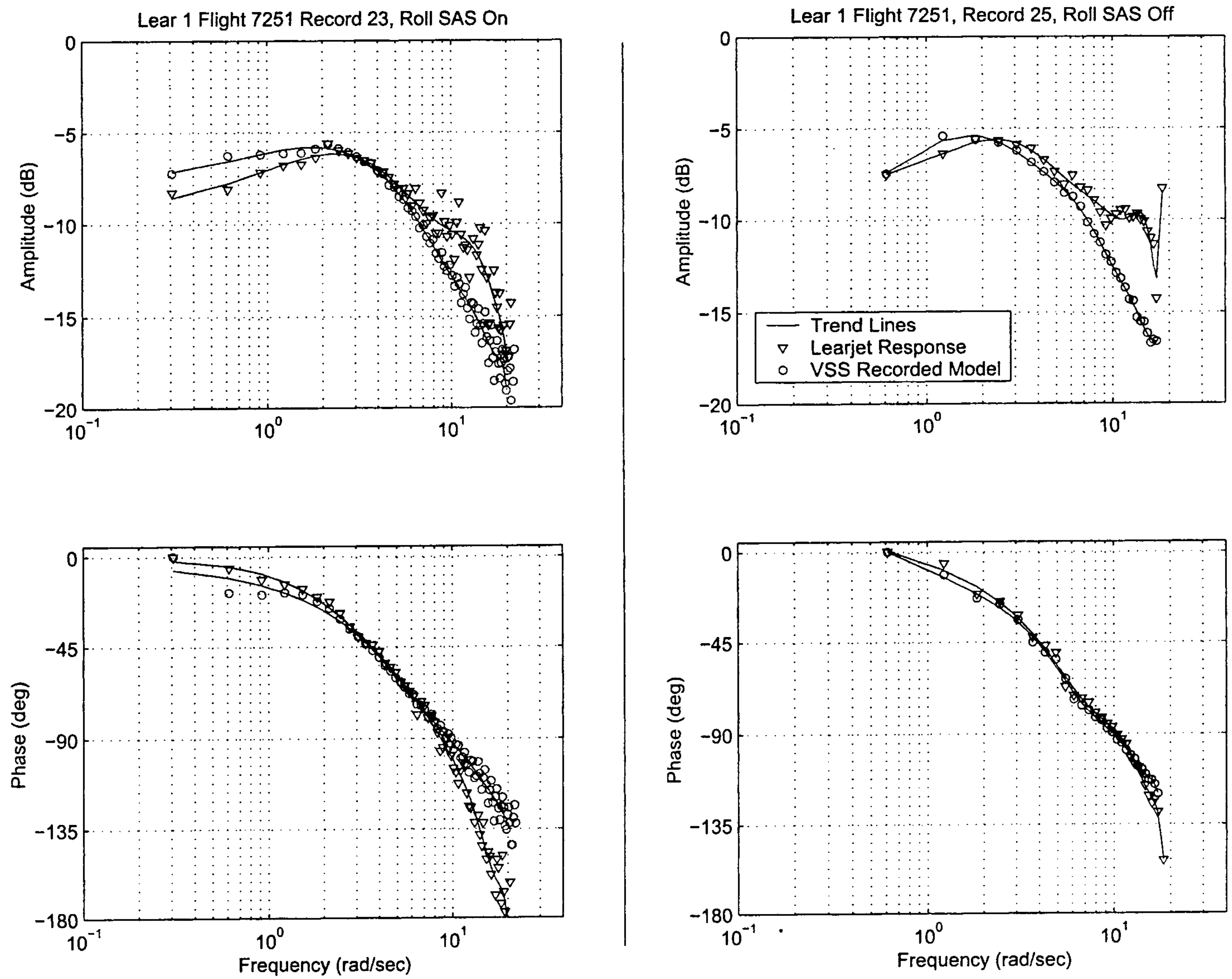
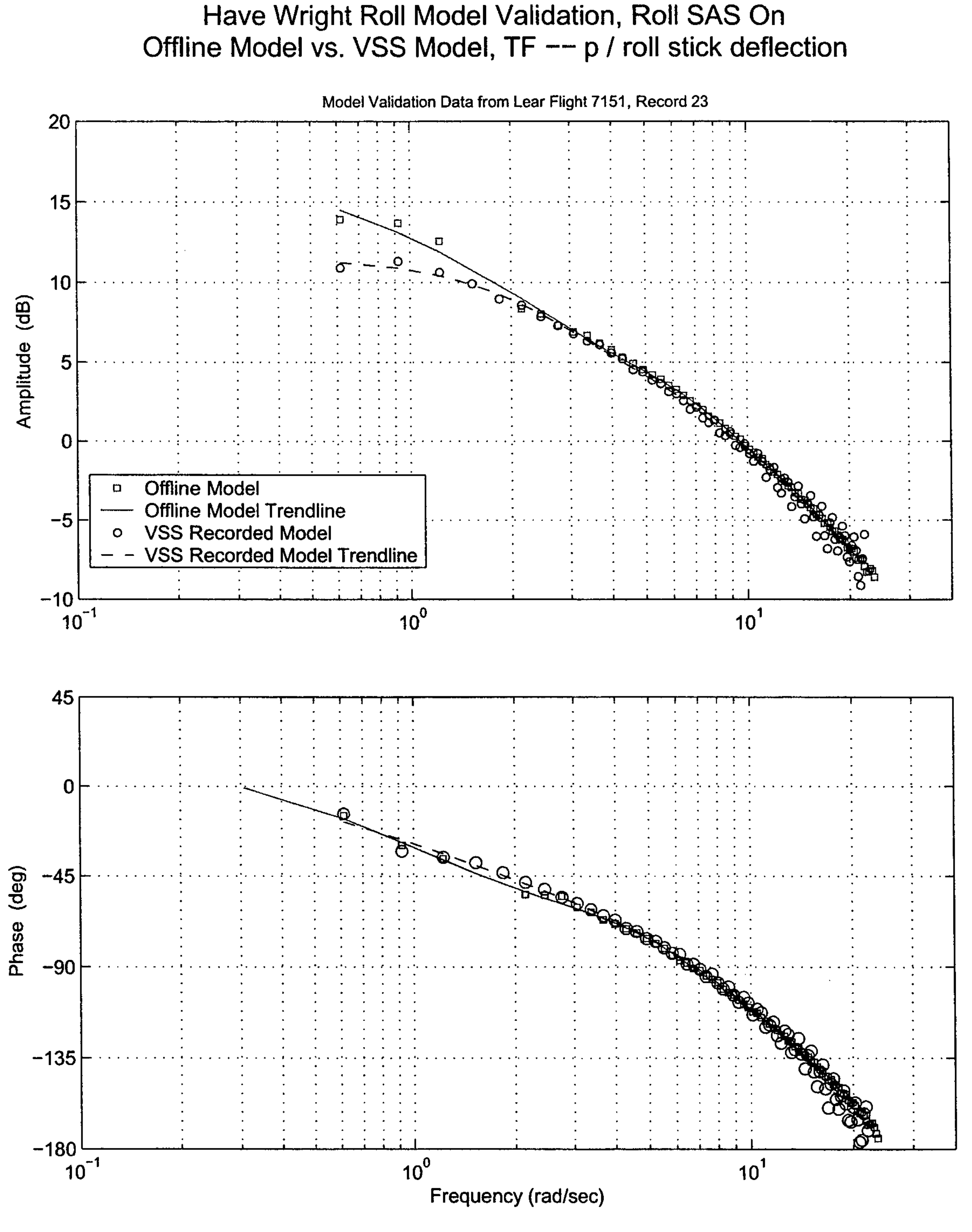


Figure 20. Frequency Domain Model–Following Verification – Roll Axis

**Figure 21. Frequency Domain Aerodynamic Model and FCS Validation – Roll SAS On
VSS Recorded Model vs. Offline Model**



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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviation	***Definition***
AFB	Air Force Base
AFFTC	Air Force Flight Test Center
AGL	Above Ground Level
AIAA	American Institute of Aeronautics and Astronautics
ARI	Aileron Rudder Interconnect
CHR	Cooper-Harper Rating
DAS	Data Acquisition System
EDW	Edwards Air Force Base
ft	feet
HQDT	Handling Qualities During Tracking
hrs	hours
KIAS	Knots Indicated Airspeed
kts	knots
MOP	Measure of Performance
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
PA	Pressure Altitude
PIO	Pilot In-the-Loop Oscillation
PIOR	Pilot In-the-Loop Oscillation Rating
PMD	Palmdale Airport
PTI	Programmed Test Input
RNoAF	Royal Norwegian Air Force
RTO	Responsible Test Organization
sec	seconds
SpAF	Spanish Air Force
SAS	Stability Augmentation System
TPS	Test Pilot School
TIM	Technical Information Memorandum
TW	Test Wing
USAF	United States Air Force
USAF TPS	United States Air Force Test Pilot School
USN	United States Navy
VMC	Visual Meteorological Conditions
VSS	Variable Stability System
VVSLIS	Veridian Variable Stability Learjet 24 In-flight Simulator
WRI	Warp Rudder Interconnect

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3 March 2003

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ADB 267 982
A LIMITED HANDLING QUALITIES EVALUATION OF AN IN-FLIGHT SIMULATION OF THE 2003 WRIGHT FLYER, HAVE WRIGHT. AFFTC TIM 01-07.

2. The report was cleared for public release by the AFFTC Public Affairs Office (AFFTC/PA) on 18 January 2003, PA #03-006. (See attached clearance letter.)

3. Should there be any questions, please contact me at (661) 277-3606 or DSN 527-3606.

Jolaine Lamb

JOLAINE LAMB
AFFTC STINFO